The WELDING JOURNAL

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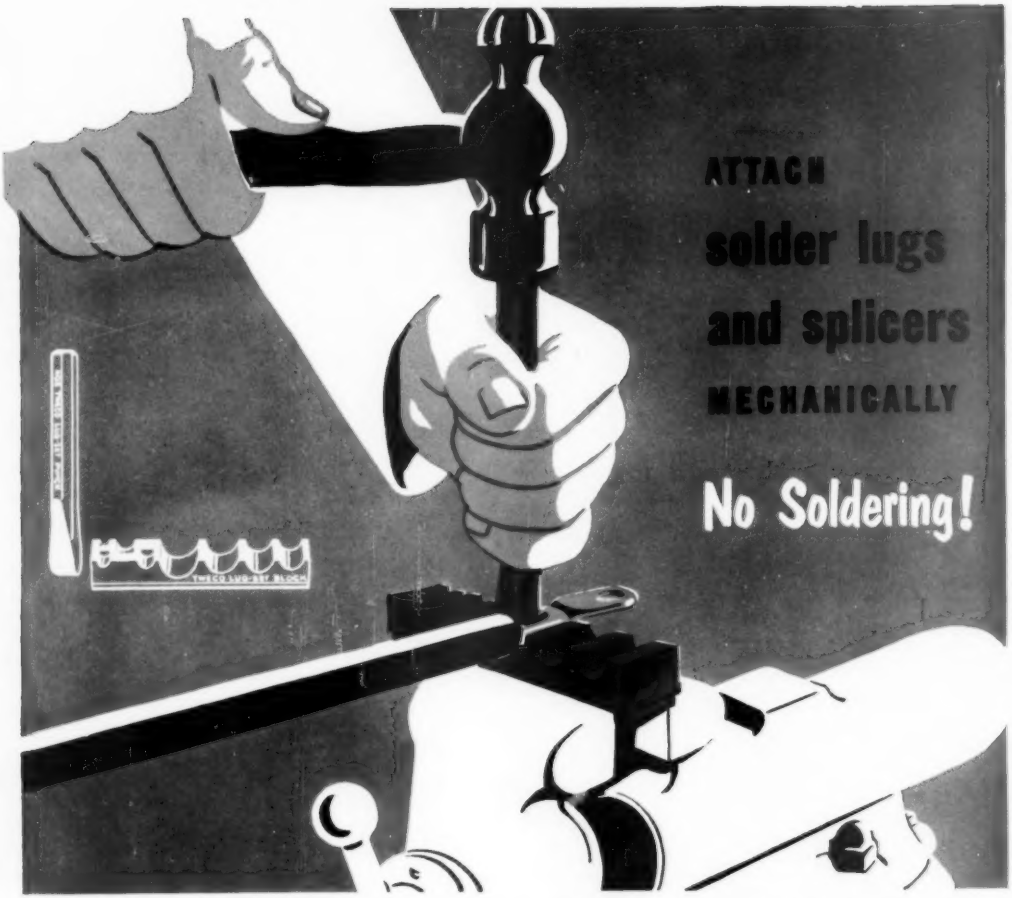

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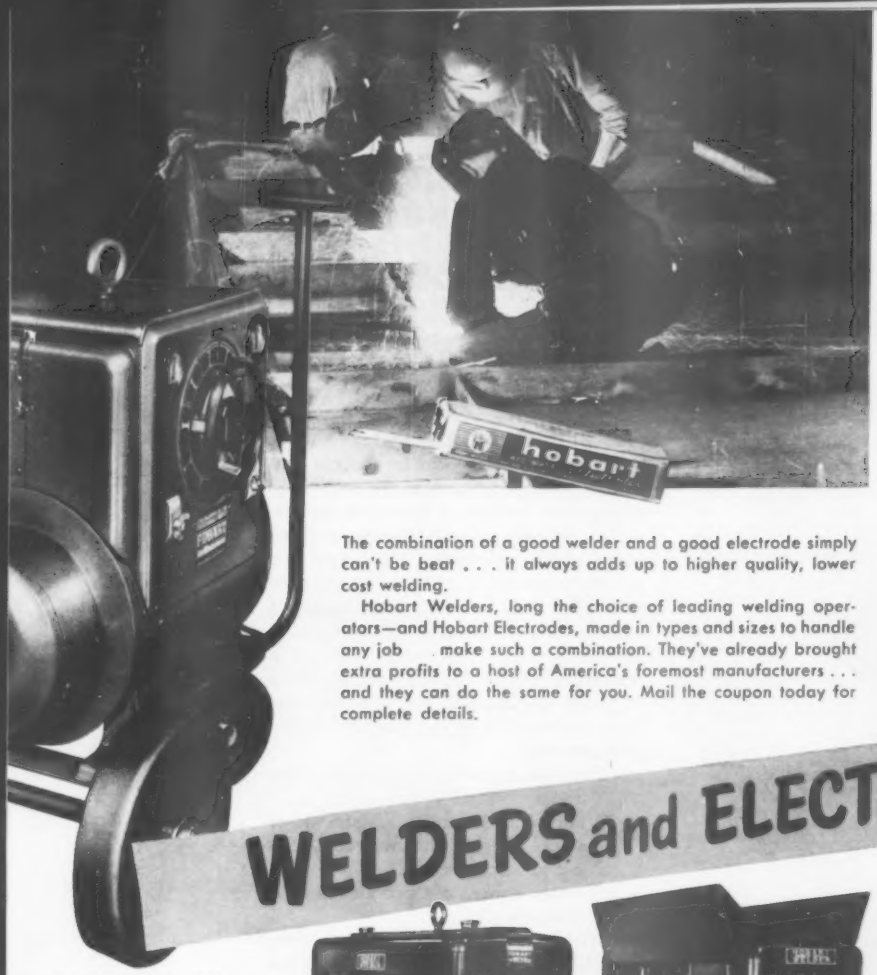

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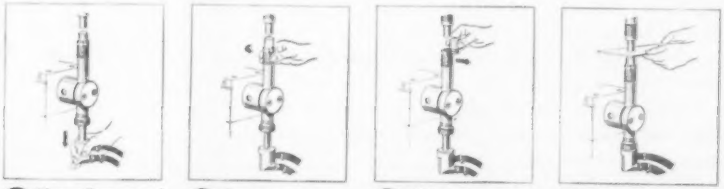

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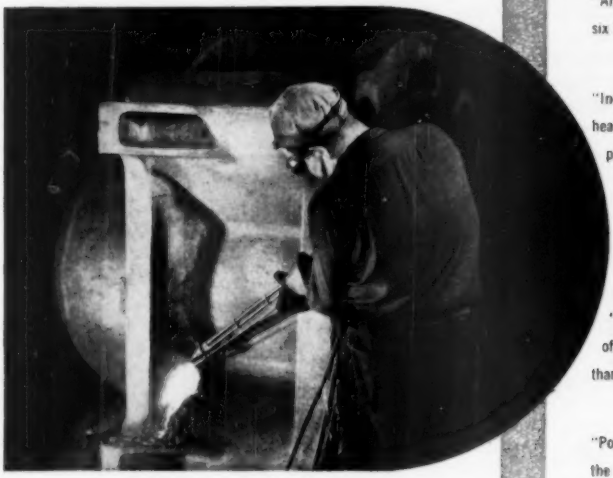

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The WELDING JOURNAL

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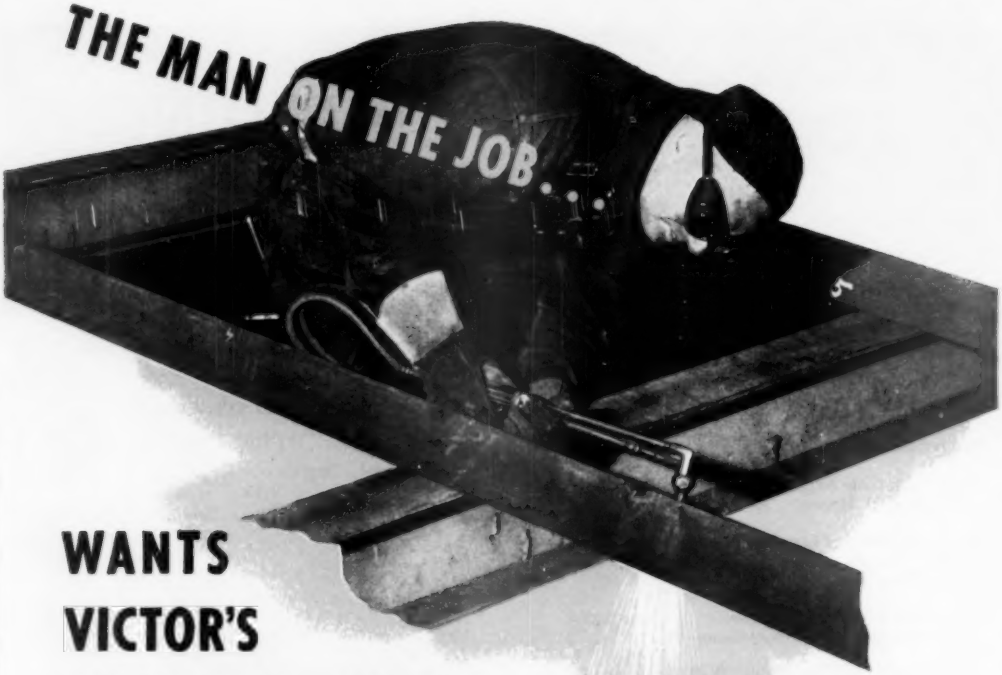

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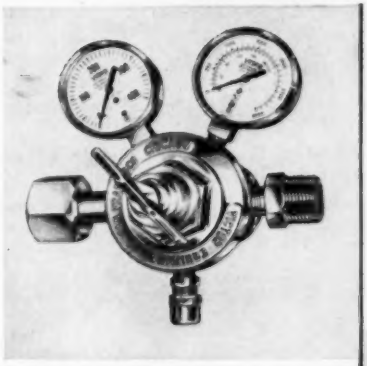

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The WELDING JOURNAL

volume 31 September 1952 number 9

Production Brazing

Information regarding production brazing processes, brazing filler metals and some specific application of furnace brazing and induction brazing

by J. Raymond Wirt

A BRAZE is defined by the AMERICAN WELDING SOCIETY as "A weld wherein coalescence is produced by heating to suitable temperatures above 800° F and by using a nonferrous filler metal having a melting point below that of the base metals. The filler metal is distributed between the closely fitted surfaces of the joint by capillary attraction."

Braze weld is essentially the same but the filler metal is not distributed by capillary attraction.

These terms are the basic foundation for a high dollar volume of production work which is saving industry millions of dollars annually and is responsible for the economical production of intricate parts which in a large number of cases could not be made economically any other way. Parts produced daily, running in size from jewelry to airplane propellers, have been adapted to the efficient use of brazing.

Some of the materials being brazed are aluminum, magnesium, brass, copper, steel and cast iron. There are eight different brazing processes named on the "Master Chart of Welding Processes" issued by the AMERICAN WELDING SOCIETY, which are classified according to the method of heating. There are 33 brazing filler metals also listed by the AMERICAN WELDING SOCIETY as being used in quantity which vary in composition from pure metal to four or more alloying constituents to give a wide range of liquidus and solidus temperatures with various properties and applications. These materials are listed with a "B," meaning brazing filler metal, followed by the chemical symbol of the principal ingredients. See Chart A for listing of processes and materials which is the author's version of a chart produced for the new *Brazing Handbook* by the Brazing Committee of the AMERICAN WELDING SOCIETY.

Of the high production processes one of the most universally used is controlled atmosphere furnace brazing of mild steel, using copper as the brazing filler metal. The original outlay for the furnace and atmosphere generator is high but the versatility and efficiency of the equipment is good and unskilled operators may be used to prepare and load the parts.

When the parts are properly designed to give interference fits or are riveted, staked or tack welded to give intimate contact between the surfaces to be joined and the proper procedure is used, the joint is composed almost completely of iron copper alloy with very few pockets of copper remaining. The residual copper is fully annealed, of large grain size and is low in strength, especially at elevated temperatures. After the braze is completed the iron copper alloy is strong and not appreciably affected in strength by temperatures below 800° F.

Production rates on atmosphere furnaces are dependent on the heating and cooling capacity of the furnace as translated into parts with their fixtures and also on the ability of the operator to load the parts.

Theory is excellent but unless it is applied no good can be realized. As examples of applications, Fig. 1 shows tungsten disks used for contact surfaces which are copper brazed in a controlled atmosphere furnace to the steel rivet or breaker arm as shown. The brazing filler metal is the copper disk shown in the exploded view of the assembly. Figures 2 and 3 show the typical brazing furnace used for this operation. The heating and cooling zones are shown.

To show that large parts as well as small may be

J. Raymond Wirt is Welding Engineer, Process Department, Delco-Remy Division of the General Motors Corp., Anderson, Ind.

Scheduled for presentation at the Thirty-Third Annual Meeting, AWS, Philadelphia, Pa., week of Oct. 20, 1952. Closing date for discussion, Nov. 15, 1952.

Chart A The author's version of information compiled by the Brazing Committee of the AMERICAN WELDING SOCIETY. "B" symbolizes brazing filler metal, while the remainder is the chemical symbol of the principal ingredients of the metal

BASE METALS / PROCESS	Aluminum and Aluminum Alloys	Magnesium and Magnesium Alloys	Nickel and Nickel Alloys	High Carbon and Tool Steels	Stainless Steel	Cast Irons	Copper and Copper Alloys	Carbon and Low-Alloy Steels	Heat Resistant Alloys	Ag, Au and Pt
TORCH	BAlSi	BMg	BAg BCuZn	BAg BCuZn	BAg BCuZn	BAg BCuZn	BCuP BCuZn BAg	BCuZn BAg	BAgMn BCuZn BAg	BCuAu BCuP BAg
TWIN CARBON ARC	BAlSi	BMg	BAg BCuZn	BAg BCuZn	BAg	BAg BCuZn	BCuP BCuZn BAg	BCuZn BAg	----	----
FURNACE	BAlSi	BMg	BNiCr BAgMn BCu BAg	BAg BCu BCuZn BNiCr	BAg BNiCr BAgMn BCu	BAg BCuZn	BCuP BCuZn BAg	BCu BCuZn BAg BNiCr BAgMn	BNiCr BAgMn BAg BCuZn BCu	BCuAu
INDUCTION	BAlSi	BMg	BAg	BAg BCuZn	BAg	BCuZn BAg	BCuP BCuZn BAg	BCuZn BAg	BAgMn BAg BCuZn	BCuAu
RESISTANCE	BAlSi	——	BAg BCuZn	BAg	BAg	——	BCuP BCuZn BAg	BCuZn BAg	BAg	BCuAu
DIP	BAlSi	BMg	BAg	BAg BCuZn	BAg	BAg BCuZn	BCuP BCuZn BAg	BCuZn BAg	——	——
BLOCK	BAlSi	BMg	BAg	BAg BCuZn	BAg	BAg BCuZn	BCuP BCuZn BAg	BCuZn BAg	——	——
FLOW	BAlSi	——	——	——	——	BCuZn	BCuZn	BCuZn	——	——

Note: Filler metal symbols used refer to standard AWS-ASTM classification numbers.

successfully brazed in production, Fig. 4 shows the size of the assembly as judged by the man in the picture. Figure 5 is a cutaway view of the propeller blade showing the three lands used for the junction. Figure 6 shows the metal spray gun used to deposit the copper brazing filler metal with the shield in place to minimize the deposition of excess copper. Figure 7 shows the blade in position in the nickel cast-iron fixture at the entrance to the controlled atmosphere furnace. Alignment and pressure are furnished by the fixture.

Another assembly method is shown in Fig. 8. The fan and pulley assembly are held together by staking the hub in the punch press fixture as shown. Copper shavings are dispensed from the hopper in the center of the picture. The assembly is then placed on the furnace belt.

In addition to copper brazing of mild steel, atmosphere furnaces with proper variations in atmosphere and temperature are used for brazing aluminum, cast-iron, brass, stainless and low-alloy steels, using the proper brazing filler metal.

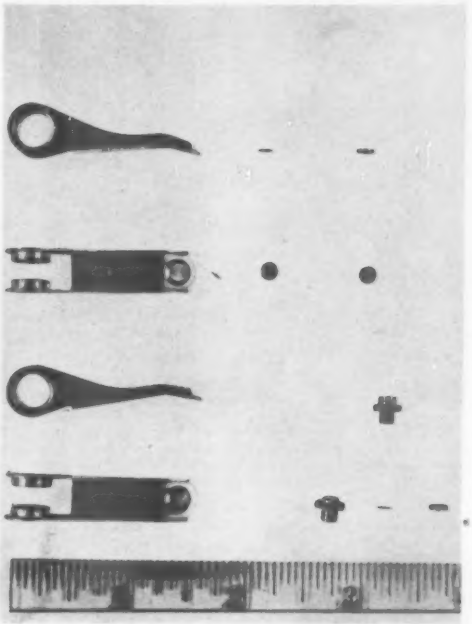
Cast iron is often brazed using brass as the filler metal. At the temperature used for copper brazing some of the constituents of the cast iron may be softened but at the brazing temperature for brass no ill effects are observed.

Aluminum requires very close temperature control and relatively low rate of heat input since the brazing temperature is only 15 to 50° F below the melting temperature of the base metal.

Brass generally requires the use of silver-alloy brazing material to avoid excessive distortion of the parts.

Stainless and low-alloy steel may be brazed using either copper or the silver alloys except the phosphorus-bearing alloys since phosphorus and iron combine to form iron phosphide which is brittle.

The process which is used to produce the largest total volume of brazed parts is torch brazing. The total volume consists of a large number of applications of low production parts combined with some high production parts which require individual attention of an operator to secure sound joints.



Courtesy of P. R. Mallory & Co., Inc.

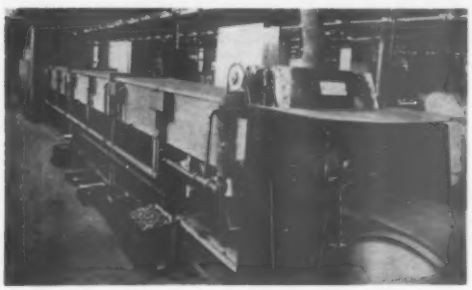
Fig. 1 Tungsten disks copper brazed to steel support

The copper wafer used as brazing filler metal is shown in the exploded view of the contact rivet and of the breaker arm

The heating equipment is relatively inexpensive; it is versatile and does not require the services of skilled operators as a rule. Copper brazing is not successful by this method but most of the brazing filler metals which melt at temperatures below copper are successfully used with a torch.

The fuel gases used are listed according to the heat obtainable, the hotter combinations being listed first:

1. Oxy-acetylene.
2. Oxy-hydrogen.
3. Acetylene and air.
4. Natural or bottled gas and oxygen.
5. Natural or bottled gas and air.



Courtesy of P. R. Mallory & Co., Inc.

Fig. 2 Discharge end of controlled atmosphere brazing furnace

Courtesy of P. R. Mallory & Co., Inc.

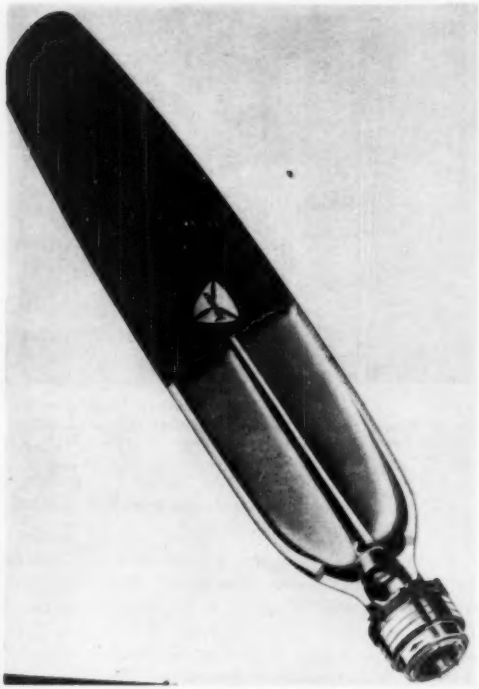
Fig. 3 Entrance or heat zone end of controlled atmosphere brazing furnace used to braze the parts shown in Fig. 1

(a) Ceramic burners using premixed mixture.
(b) Injector mixed gas.

For small production runs a hand torch with simple fixturing produces economical parts. For larger runs fixed burners either singly or in groups with the parts moving through give optimum production. The original cost of such a machine depends on the production, the complexity of the parts and the filler metal used. Because of the high heat input from multiple flames, aluminum parts are generally difficult to braze on an automatic setup.

Courtesy of Aeroproducts Division, General Motors Corp.

Fig. 4 Airplane propellers which are copper brazed. Compare size with parts in Fig. 1

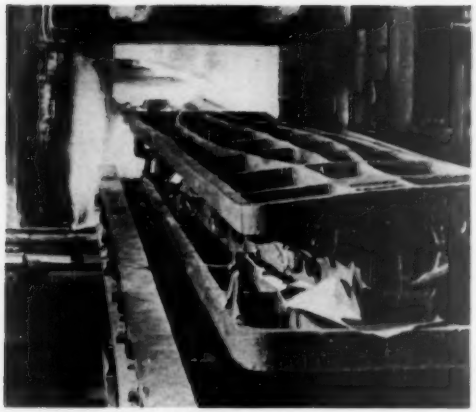


Courtesy of Aeroproducts Division, General Motors Corp.

Fig. 5 Cutaway view of the propeller blade showing three lands used for brazing

Induction brazing is a very efficient method of brazing where fairly high production requirements justify the expenditure for the generators and the fixturing. The parts produced are clean and the labor per part is low. The most efficient production method involves the preplacement of filler metal in the shape of rings, powder or strip, flux and the use of loading mechanisms such that the parts are loaded outside the heating coils then introduced into the heat zone.

Figure 9 shows a twin station installation in which



Courtesy of Aeroproducts Division, General Motors Corp.

Fig. 7 The propeller blade is in position in the fixture used for brazing at the entrance to the controlled atmosphere furnace

the parts are prepared and loaded on one station while the parts on the other are heating. Figure 10 shows a conveyorized application in which a capillary tube is silver brazed to a cold control frame. The machine indexes six stations by the time the parts are assembled, then indexed into position where a piece of alloy about $^1/_8$ in. long is automatically cut off and placed inside the retaining boss. The parts then move into the heating coil, are brazed and then moved into a washing position where the excess flux is removed, and finally into a drying position where warm dry air is circulated to minimize staining, then they are unloaded. The production is six parts every 8 sec or 2700 parts per hour at 100% efficiency.

Resistance brazing is a fast, economical method in which the heat input rate is adjustable and the time may be controlled. One type power source is a transformer with a standard resistance welder timer added. The heat is generated by the resistance of the parts and the electrodes. If it is found that water-cooled copper alloy withdraws the heat too rapidly carbon or re-

Courtesy of Aeroproducts Division, General Motors Corp.

Fig. 6 Metal spray gun used to deposit the copper necessary for brazing

Fig. 8 Fan and pulley assembly staked in punch press before the copper powder is added and the assembly brazed in the controlled atmosphere furnace

Courtesy of Induction Heating Corp.

Fig. 9 Double-station induction brazing parts

Note parts are prepared and loaded on one station while parts on other station are heating

fractory faced tips serve two purposes: they generate additional heat and also serve as a thermal insulator from the water-cooled portion of the electrode.

For parts which have relatively high resistance such as mild steel or stainless steel and are thick enough to retain the heat at the brazing zone, the electrodes used are not too important. However, on copper and copper alloys such as brass, etc., whose resistance is so low that very little heat is generated in the parts, the electrodes must be faced with low-conductivity material such as copper tungsten carbide, molybdenum, tungsten or copper tungsten or consist of carbon to give enough heat to braze. A typical brazing setup is shown in Fig. 11. The upper electrode is faced with molybdenum and the lower is a carbon block mounted in a water-cooled die. One part which is brazed consists of a flat brass plate about $^1/_8$ in. thick joined to a copper stud about $^1/_2$ in. in diameter and 3 in. long. Silver alloy, 50% in strip form is used with flux. The pro-

Fig. 11 An electro brazing job set up in a 50-kva resistance welder

Strip-silver alloy is used as the brazing filler metal, flux must be used. A carbon lower electrode and molybdenum upper electrode are used to generate sufficient heat to secure a sound joint since a heavy copper stud is brazed to a flat brass plate. Production is 200 parts per hour net

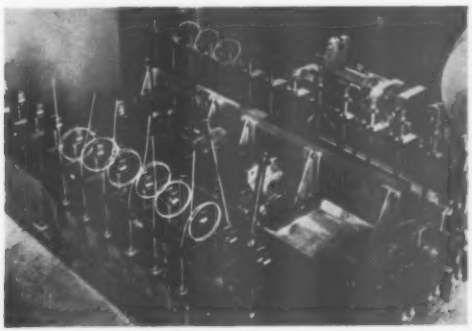


Fig. 10 Automatic indexing machine for induction brazing with silver-alloy filler the copper tube to a steel bracket

Filler metal is fed automatically as is the flux. The parts are revised to remove flux before they are unloaded

Fig. 12 An application of braze welding in which a strip 0.003 in. thick by $^1/_8$ in. wide silver, phosphorus ribbon is fed out automatically each time the welder head goes up

The coils are positioned by the operator under the molybdenum-faced electrodes. Production is 600 assemblies per hour which is both faster and cheaper than the former soft solder junction

duction is 200 assemblies per hour with one operator which compares with 55 per hour with a torch.

Other forms of resistance brazing equipment are tongs and portable guns. However, parts which are to be aligned can best be held in a standard resistance welder.

Braze welding is performed in the same type of machine using filler material in strip form. The material used in the job shown in Fig. 12 is copper, silver and phosphorus. The strip is 0.003 in. thick and after braze welding the alloy remaining is about 0.0001 in. thick. The conductivity of the brazing filler metal is about 14% that of copper which assists the molybdenum-faced electrodes to generate sufficient heat to make the braze weld in 5 to 8 cycles. This short time will not allow the filler metal to distribute itself by capillarity which places this joint in its classification as a braze weld rather than a braze. Production on this job is over 600 assemblies per hour with one operator. No flux is used since the phosphorus acts as a fluxing agent. This application is faster than soft soldering, saves almost 1 in. of copper per assembly and is cleaner since no flux is used. We have been using this method for over 3 yr. with excellent results, both structurally and economically.

Dip brazing is widely used, especially in aluminum work. Molten flux or neutral salt is used as the bath. When the parts are of thin section, of intricate pattern and so designed that the filler metal can be preplaced with the assembly either staked or tacked together or so designed as to be self locating or held properly in a fixture, the even heat will allow fast efficient brazing. The original equipment cost is not too high but the drag out of salt on large intricate parts is high. If the parts are allowed to hang over the bath in the relatively hot area near the surface, a maximum amount of the salt will be recovered. However, if labor costs more than the drag out of salt the extra time will not be economical.

Block brazing is used where parts must be accurately held during brazing. The blocks are heated and held in place by pressure to assure conformation of the parts being brazed. An example of the use of this process is the brazing of heat-conductive bottoms to cooking utensils.

Twin carbon arc and flow brazing are used in production to a lesser degree than preceding processes. Both of these processes are more applicable to braze welding than to brazing.

The AMERICAN WELDING SOCIETY Committee on Brazing and Soldering is preparing an *Inspection Handbook on Brazing* similar to that on arc welding which will cover these and other applications of brazing.

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Observations on Experience with Welded Ships

The background of experience acquired with welded construction in the shipyards of the United States prior to the war construction program, experience during the program and the lessons learned from that experience

by David P. Brown

FROM reports and statements which have been made from time to time as a result of the very spectacular and consequently greatly publicized failures of some welded seagoing ships, one is very liable to get the impression that welding in the shipbuilding field in the United States was adopted strictly as a wartime necessity. The emphasis which has been placed upon the benefits of welding resulting from the ability to establish entirely new shipbuilding plants, to recruit the tremendously large numbers of hitherto untrained workers to man these plants and to produce ships quickly on a mass production basis as was so necessary for the successful prosecution of the recent World War may have led many to believe that these were the predominant factors leading to the adoption of welding as a medium for the construction of ships' hulls. It is true that these conditions undoubtedly accelerated the transition from riveted to welded construction and that they have had a decided influence on the almost complete transition which has taken place in peacetime construction in the United States shipyards and the experience acquired has no doubt had some influence on the corresponding trend in the shipbuilding plants in many other parts of the world.

WELDING IN THE PRE-WAR PERIOD

For many years prior to the war emergency period, ship designers had recognized the many attractive possibilities of the application of this new medium for joining the many structural parts comprising a ship's hull. It has always been the object in all sound engineering designs to strive for the most economical structure, from the standpoint both of first cost and maintenance, which will satisfactorily perform the services for which it is intended. In the fields of stationary structures such as storage tanks, bridges, buildings, etc., the problem is generally primarily one of obtaining a balance between first cost and maintenance, economy of material and resulting final weight of structure being of secondary importance only in so far as they affect these two factors. In a ship's structure, however, where the container and its contents are expected to be in transit for a good part of the useful life, every pound of redundant material represents a potential reduction in the earning capacity of the ship spread over its entire service career. Practically all seagoing commercial ships of large size are limited in the total weight of the container and contents by International load line Regulations which place a limit on the depth to which they can be loaded and in many cases further limitations may be imposed as a result of available depths of water at the terminals or in channels or canals. Even in those cases where draft limitations may not be the controlling factor, such as in the case of a light ship proceeding in ballast or when carrying a light cargo using all available cubic, redundant weight in the hull structure is reflected by added fuel costs or reduced speed in transit. A great many owners and operators also recognized the possibilities offered by welding in the elimination of some of the nuisance repairs with which they had been faced with riveted ships. It is not an uncommon experience to find, on periodic examinations of these ships, large numbers of rivets which require renewing on account of an advanced degree of wastage of the rivet points or owing to their having become loosened as a result of slamming in heavy seas or working in highly stressed areas.

It is no wonder, therefore, that even before the war emergency conditions added impetus to the use of welding in shipbuilding, great strides had been made in its adoption. In 1917 when the shipyards of the United States were confronted with the necessity of producing ships in large quantities, the authorities having charge of the construction program appointed a committee to consider the construction of welded ships in view of the, then, general belief that the chief obstacle to the construction of large quantities of steel ships was the lack of trained riveters. Plans were prepared for a standard type of 2-deck cargo ship, 401 ft long, 54 ft beam and 32 ft 10 in. deep. It was proposed to construct the ship in transverse sections each 6 ft long and comprising a double bottom section plated transversely, a side section plated vertically and deck

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sections plated transversely. The keel, center girder and rider plate, the bilge strakes, the sheer strake and deck stringer plates were plated longitudinally in 30-ft lengths with the idea of reducing the number of joints in these important members. A contract was given to one of the shipyards for the construction of a full-size experimental mid-section subassembly and the work was well under way at the time of the Armistice in 1918. About two weeks before the Armistice, authorization was given for the construction of a complete all-welded vessel but shortly after the Armistice both of these projects were cancelled. This was, in my opinion, very unfortunate since the experience which might have been gained in the construction of a large all-welded ship, especially if combined with a satisfactory service record, would have undoubtedly accelerated the application of arc welding to ships under peacetime conditions and in a more orderly manner than was possible during the recent war years.

The deliberations of this Committee had one important result in that some of its prominent members, realizing the need for a Technical Society devoted exclusively to the study of welding problems, took steps which led to the formation in 1919 of the AMERICAN WELDING SOCIETY, which has since done so much to promote and advance the science and art of welding in American industry and which, through its affiliations with other similar groups throughout the world, has made available a world-wide exchange of information relating to research work and new developments in the field of welding.

During this era the use of electric arc welding in shipbuilding was generally confined to repair work, to the rectification of defects and in the case of new construction to those parts of the ship which were considered to be structurally unimportant; such items being listed by the Classification Societies as a guide for their surveyors. Failures of welds due to improper equipment or unskilled workers were not uncommon and these served to prejudice many shipbuilders with a background of riveting against the use of welding and served to delay its more general adoption. Fortunately, however, there were a number of individuals—not only those primarily interested in the promotion of welding but also among shipbuilders and shipowners—who, recognizing the economic advantages of this new medium, were not content with this state of affairs, and some of the leading shipyards in the United States inaugurated pioneer experimental work in their own plants and instituted schools for the training of welding operators with the result that an ever increasing amount of welding was done in succeeding merchant ships.

In 1921 there was built in England what is purported to be the pioneer all-welded seagoing merchant vessel, named the *Fullagar* and later named the *Shean*. She was a very small vessel being only 150 ft long by 23 ft 9 in. beam by 11 ft 6 in. deep. She operated for a number of years in the coasting trade during which she suffered the usual mishaps including a severe grounding and later she crossed the Atlantic and was placed in coasting service in British Columbia. This vessel performed a very useful service until the summer of 1937 when she was sunk following a collision.

In the field of small vessels, during the middle 1920's, the development of welding as a substitute for riveting took place rapidly in the United States, particularly in the case of small tankers operating in river and harbor service, where superior oil tightness and freedom from the usual rivet troubles, experienced as a result of frequent bumping or grounding, made this new medium attractive to the owners. The majority of such vessels were towed barges of simple rectangular cross section with rake ends in which nearly all of the work was straight work and in which the assembly and erection problems are simple as compared with a vessel of ship form.

In 1927 the American Bureau of Shipping, with which Society the great majority of these vessels were being classed, decided that it was prepared to express a degree of confidence in this type of construction as is necessary to obtain the highest classification so that the Rules of that year provided for the classification of all-welded ships with a notation "Metal Arc Welded" after the usual classification symbols, it being considered that any reference to the classification being experimental was quite unwarranted.

Following these meager beginnings, the use of welding was continuously extended to somewhat larger vessels including the coastwise types of self-propelled tankers of ship-shape form with the result that, by 1940, riveted construction of all types of floating equipment of under 300-ft length had practically disappeared, all of these smaller vessels being completely welded. Experience gained in the construction and operation of small all-welded coastwise tankers gave the builders and the owners of several vessels of this type confidence to go ahead with the welded construction of a large oceangoing tanker in 1937. This vessel, the *J. W. Van Dyke*, was 521 ft long by 70 ft beam by 40 ft deep, had a deadweight capacity of 18,105 tons and a gross tonnage of 11,650. The construction of this vessel constitutes a milestone in the development of welded construction for ships' hulls since it represents the first application of welding to a hull structure which required the use of materials of thicknesses approaching those as are now commonly required in the modern large welded merchant vessels, and many of the details of the structure compare very closely with those which are still being followed. In addition, it was in the construction of this vessel that automatic welding on a large scale was first used in shipyard work. In this first vessel of its type the ends beyond the cargo tank spaces were generally of riveted construction, but in the construction of succeeding vessels immediately following the *Van Dyke* the riveting at the ends was replaced by welding so that this particular vessel might be said to be the prototype of our modern large all-welded tankers.

The establishment in 1937 of a Maritime Com-

mission in the United States with authority to inaugurate a long-range shipbuilding program at the rate of 50 ships per year over a 10-yr period gave added impetus to the use of welding in ship construction. A number of the established shipyards participating in this program had available a nucleus of personnel trained and experienced in welding, resulting from continuous experimentation and the increasing use of welding in their plants, and the Commission very properly decided to allow the various builders to rivet or weld as they saw fit. These contracts were spread throughout all of the then existing shipyards in the country and they generally called for only four to six ships of one type in any one particular yard. Under the option permitted by the Commission the different yards elected to use welding in widely varying degrees from the practically all-riveted ship to the all-welded ship. With the outbreak of hostilities in Europe, it was recognized that the demands on the merchant tonnage of the world would be tremendously increased and authority was granted to the Maritime Commission to accelerate the construction program with the result that a large number of additional contracts were placed with the yards who were participating in the original program. The placing of firm orders for additional ships and the anticipation of still further contracts, resulted in a number of yards, who had elected to use a large amount of riveting on the original ships, replanning their designs for the new orders to take advantage of the large subassembly system of construction in association with more and more welding.

WELDING IN THE WAR-EMERGENCY PERIOD

As a result of these activities, by the time the shipbuilding industry was confronted with the necessity of greatly expanding the building capacities to meet wartime emergency demands, welding had become almost universally adopted and it was no wonder that when the British Government decided to supplement the already overtaxed shipbuilding facilities in the United Kingdom and Canada by arranging to have 60 vessels built in the United States, the two new plants established to build these vessels were laid out and equipped for building all-welded ships. These two plants were the forerunners of a number of such plants which were built in the years immediately following and in which there were produced during the war years the miraculously large numbers of Liberty Ships, Victory Ships and T2 Tankers.

In one way it is perhaps unfortunate that the shipbuilding industry should have been required to plunge into the wholesale adoption of welding under wartime emergency conditions before having acquired any real length of service experience with large all-welded ships built under more normal conditions, since some such experience might possibly have pointed at some of the pitfalls into which we innocently fell. On the other hand, the building of so many ships, identical in design, has afforded those of us who have access to the service records of these ships, an opportunity of analyzing the different structural difficulties and of avoiding false conclusions which might have been arrived at from only one set of circumstances. Never before in history have there been so many vessels of one type operating under the varying conditions all over the world and it is by a continued study of reports of damages that we have been able to isolate certain factors contributing to these damages to the end that these can be eliminated or circumvented.

For instance, were we to have only 20 ships identical in every respect and a structural failure, either serious or inconsequential should develop in only one of these ships, it is not believed that, unless there should be a glaring defect in design, one would consider it necessary to adopt corrective measures for application to the other 19. However, when we are observing records covering over 400 identical vessels such as in the cases of the Victory ships, nearly 500 in the cases of the T2 tankers and of over 2500 as in the case of the Liberty ships any type of structural trouble, if there is some inherent fault involved, has a far greater chance of being repeated several or even a large number of times and through such repetition the finger is oftentimes pointed at the fault, and corrective measures which can be applied to the remaining ships or at least to subsequent ships are in many cases quite definitely indicated.

Even if all-welded construction had had a long background of experience prior to the commencement of the war emergency program, it would not be unreasonable to have expected some difficulties with the ships built under this program. The magnitude of the program was considerably beyond the normal capacities of the shipbuilding industry in the United States and it was necessary to construct entirely new yards, to recruit and train labor from all walks of life including many workers who had had no previous association with the hard manual labor involved in shipyard work. The management and supervisory personnel were for the most part drawn from the established shipyards who were already working to capacity and as a result it was necessary to spread very thinly the actual "know-how" of shipbuilding. It is, therefore, not surprising that there would have occurred some serious failures in these warbuilt ships, whether they had been riveted or welded, and the relatively small number of serious failures among the more than 4000 predominantly welded ships is less to be wondered at than the entirely satisfactory service provided by the remaining thousands. Failures of varying degree of severity have occurred in all types of ships ever since ships have been built and these failures have been an ever present challenge to the designers. While in this paper, reference may often be made to failures in welded ships, it is not intended to create the impression that there is any distrust of the use of welding as a medium for the construction of ships' hulls, but it is only through a proper recognition and study of the failures that designers and builders can provide

the necessary safeguards against their repetition.

EARLY CASUALTIES

The first Liberty ships produced in the newly created emergency shipyards were placed in service near the end of 1941. They were being rapidly produced from that time on so that by the middle of January 1943 there were in service approximately 500 of this type of vessel. Up until that time there had been accumulated reports covering 10 fractures in the hull structure which were considered to have occurred in such locations and to such extent as to cause concern as to the safety of the vessel, most of these having occurred during the more severe weather conditions of the late fall of 1942 and the start of the 1942–43 winter season. These fractures were being made the subject of very serious study by the staff of the American Bureau of Shipping, with whom these vessels were classed, when the whole problem of welded ship failures was highlighted by the spectacular breaking in two on Jan. 16, 1943 of the T2 tanker *Schenectady* while lying at the builder's outfitting dock shortly after having completed her trials. The nature and extent of the break of this vessel was certainly without precedent in shipbuilding history and it occurred without apparent provocation. The vessel broke across the deck just abaft the after end of the bridge about amidships, the fracture extending down both sides and around the bilges to the bottom shell plating which remained intact. All deck, side and bottom longitudinal frames fractured as did also the plating of the corrugated longitudinal bulkheads and the heavy deep girders on the centerline at the deck and bottom, thus constituting a complete failure except for the flat portion of the bottom shell plating. In no case did the fractures occur in the transverse welds.

In most cases of fractures reported prior to this incident the finger of suspicion had been pointed at specific design details, such as square hatch corners or square cutouts in plate edges at highly stressed locations, which, coupled with inferior workmanship, had quite apparently been the cause of the fracture and corrective measures were beginning to be quite clearly indicated. However, in the case of the *Schenectady* these conditions were not so readily apparent and there were implications that there was something rather more fundamental in the susceptibility to fracture of the large monolithic structure created by welding. In realization of the seriousness of these implications the American Bureau immediately appointed a committee of experts in welding and shipbuilding to investigate the causes of the *Schenectady*'s failure. In its investigations this committee found no basis for believing that any of the alleged contributing factors, such as shock resulting from the breaking of an anchor chain during the trial trip, the silting of the river under the mid section of the vessel to form a bar, or a shock caused by an earth tremor, could have had any bearing in the case. The report of this committee presented a diagnosis based upon theories of locked-in stresses which have proved to be of such controversial nature in the years since this fracture and on which there is still considerable disagreement. The report stated that the principal cause of the failure was "an accumulation of an abnormal amount of internal stress locked into the structure by the process used in construction together with an acute concentration of stress caused by defective welding at the starboard gunwale in way of the abrupt ending of the bridge fashion plate, augmented by the hogging stress due to the ballasted condition." Among the contributing causes mentioned were the lack of trained experienced supervisors, welders and shipfitters resulting in departures from good welding procedures and the excessive forcing of poorly fitted subassemblies with consequent excessive welding.

On this committee was included a prominent Metallurgist and Consulting Materials Engineer from one of the large colleges and under his direction there were made complete investigations of the steel involved in the fracture. It is significant to note that through his contribution to the investigation there was first brought into prominence the question as to whether or not specifications which had always been considered satisfactory to provide steel of adequate quality for riveted shipbuilding purposes were sufficiently comprehensive to insure materials suitable for large welded structures. The investigation disclosed that there had occurred a drop in air temperature of from 38° F at 2: 30 P.M. to 23° F at 11:00 P.M., the time of the fracture. It was believed that while this drop in air temperature of 15° F over a period of $8^1/_2$ hr was not extreme as to suddenness, it did introduce a factor in respect of the increased brittleness of steel at low temperatures, a property over which the then existing hull steel specifications had no control.

Following the *Schenectady* incident there occurred a number of equally disturbing fractures in welded ships. A large Great Lakes type bulk freighter, while nearing completion at the builder's dock, suddenly fractured across the deck and part way down the sides, a Liberty ship suddenly suffered a fracture in the deck and part way down one side while being loaded at a pier, and in March 1943 another T2 tanker, a sister ship to the *Schenectady*, but built in a different yard, suddenly split in two at the entrance to New York harbor under sea conditions which apparently were very moderate.

Throughout the winter of 1942–43 additional reports were being received covering fractures occurring in the increasingly large numbers of welded ships in service but these were by no means as numerous or serious as many were led to believe from the glaring press headlines and numerous investigations. The secrecy of wartime operations undoubtedly added to the popular belief that there possibly may have been many more failures than were actually released for publication. Nevertheless, the American Bureau of Shipping felt that even only one unexplainable fracture was a matter of grave concern and their staff pursued diligently the study and classification of the reports received in an

effort to modify details and correct practices, where practicable steps were indicated.

INVESTIGATIONS OF CASUALTIES

It was apparent that the introduction of welding of the large ships' hull structures had brought forth the need for a more scientific understanding of the problems involved as, for instance, why should a minor crack once started in a defective weld or at a structural discontinuity continue in some cases to propagate with lightning speed until it resulted in the complete severance of the hull girder whereas in other cases under no less severe conditions, the crack might extend for only a few inches or feet. The United States Coast Guard in which agency is vested governmental responsibility for the safety of merchant vessels and whose functions during the war years had been placed under the Navy Department, requested the Secretary of the Navy to establish a committee with authority to conduct such investigations into the design and construction methods of welded merchant vessels as they saw fit and to initiate such research projects as their investigations might indicate as being desirable. Acting upon this request the Secretary of the Navy in April 1943 appointed the "Board of Investigation to Inquire into the Design and Methods of Construction of Welded Steel Merchant Vessels." This Board was comprised of representatives from the U. S. Coast Guard, the U. S. Navy Department, the American Bureau of Shipping and the U. S. Maritime Commission which was at that time the owner of all seagoing merchant vessels being built in the shipyards of the United States. Under the auspices of this Board there was undertaken an extensive program of investigation of all of the factors relating to the ship failure problem. Technical and statistical analyses of all casualties were carried on, a review was made of the design of each type of vessel involved, loading and ballasting conditions were checked and analyzed, sea and weather conditions on the various routes were examined and many specific investigations and research projects were initiated. In addition, close liaison was maintained with the shipyards, and with other organizations who were investigating related problems both in the United States and in Great Britain.

This Board continued these activities under its direction until July 1946 when it made a final report to the Secretary of the Navy. This report covers all phases of the many investigations carried out and presents a number of conclusions. It has now come to be regarded as a classic in the annals of welded shipbuilding and serves as a very valuable reference to many designers of welded structures in fields other than shipbuilding.

In appreciation of the tremendous volume of statistical data which would require to be assembled and analyzed, the working group which was established under this Board and which was known as the Sub-Board first decided that it would be necessary to establish certain definitions for the classification of the failures and since these have become more or less common parlance in the United States in any discussions of ship failures they are repeated in somewhat different form but in the form in which they will be used in the succeeding parts of this paper.

Casualty: A casualty consists of one or more structural fractures occurring on the same occasion on a vessel which is afloat. Unless otherwise stated, the casualty occurred under normal operating conditions and does not include fractures resulting from collisions, groundings, gun fire, torpedoes or mines.

Group I Casualty: A Group I casualty is one which includes one or more fractures in the shell strength deck or other important parts of the structure contributing to the over-all longitudinal strength of the main hull girder and which has extended to such a degree that it has weakened the structure so that the vessel is lost or is in a dangerous condition.

Group II Casualty: A Group II casualty is one which does not include any fractures comprising a Group I casualty but which includes one or more fractures in the shell strength deck or other important parts contributing to the main longitudinal strength, or in appendages thereto such as in bulwarks or bilge keels. In general, these fractures are less than 10 ft in length but they are in such locations where experience has shown they might readily have propagated into the type of fracture of a Group I casualty.

Ship-year: A ship-year is a unit for measuring the length of service records of any one ship or type of ship. It is equal to the service of one ship for one year. For example, 10 ship-years can equal 10 ships operating for 1 year, 2 ships operating for 5 years or 1 ship operating for 10 years. In citing ship-years of service records in the following parts of this paper there is included for each ship of any group, only the length of time the ship was actually active and subject to the usual surveys as required for the maintenance of classification with the American Bureau of Shipping and for which our report records are complete. For ships which have been laid up, the time during lay-up has not been counted as contributing to the ship-years of service record and for ships which have been withdrawn from class either on account of having been assigned to Military Authorities or on account of being transferred to some other classification society, their length of service subsequent to the withdrawal from class has not been included.

The Sub-Board, in accordance with American Bureau practice, included in their studies a third group of casualties comprising fractures which do not fall into the Group I or II classifications, such as those in internal structure at stanchion connections, lower decks, peak structures, etc., and in particular those in the bulkheads or web frames of tankers. Much has been written concerning these types of failures and changes in details have been pretty clearly indicated to accomplish their elimination. It is not the intention in this paper to discuss such failures but to confine the remarks to the Group I and II types and to discuss the lessons learned from them, and what measures can be and are being taken to guard against their occurrence.

For the many miscellaneous types of ships for which contracts had been awarded under the original long-range program of the Maritime Commission and which had been extended under the accelerated program and

in the construction of which permission had been granted to the individual builders to adopt welding in such degree as they saw fit, there were many different combinations of riveting and welding. The basic construction plans for the Liberty ships, which were orginally intended to be required to be followed by all of the yards building this type of ship, on account of a centralized material procurement plan, called for all parts of the structure to be welded except for the connections between the side frames and the shell plating which were to be riveted. This arrangement was generally followed in most yards but some of the builders elected from the start to weld the frames and in some of the yards changes were made at some stage of the program to eliminate the rivets and to substitute welding. Also, in the Bethlehem-Fairfield yard, where a special procurement plan was contemplated, the Commission did at the request of the builders permit the use of riveted shell seams in association with welded frames.

It is most difficult to set up any hard and fast definitions for the nature of construction to be used for statistical purposes in the comparison of service records of different types of ships. An all-welded ship or an all-riveted ship is easy of definition but one cannot clearly establish at just what stage a structure should be considered as a welded structure with some riveting or a riveted structure with some welding. However, for the purposes of this paper, it has been assumed that where all the seams and butts of the shell, inner bottom, and strength decks and all connections between these parts are welded, the ship is to be considered as being all-welded, irrespective of the method of attaching the frames. There are some who feel that the riveting of side frames may have an effect on certain conditions existing in the over-all structure, to the extent of influencing the performance in service. In the statistical studies cited in this paper, no attempt was made to make a definite separation between the ships with riveted or with welded frames, all other arrangements being alike, nevertheless some sampling of the figures failed to show any definite effects.

CONDITIONS OF OPERATION

In the investigations of welded ship problems it has generally been accepted that these could be roughly separated into four broad phases; i.e., conditions of operation, design, workmanship and materials. With regard to the first of these phases there is no doubt but that the conditions of wartime operation imposed unusual hardships on the vessels, requiring, as they did, trading in convoys, in many cases over severe sea routes which would be only infrequently used in normal times. The demands for speedy turn-arounds and the last minute assignments of cargoes which would not permit of any planning of loadings likewise contributed materially to some of the failures experienced. In some respects it may have been unfortunate that very little service experience had been acquired with welded ships up until they were required to be constructed in such quantities and operated under the exigencies of wartime service, since it is undoubtedly true that comparisons between the records of these ships and the records of prewar riveted ships operating under peacetime conditions may be masked by the conditions of operations. None but the most biased against the large scale use of welding in place of riveting can help but recognize that even had it been possible to produce such large quantities of riveted ships, constructed of materials and in accordance with designs which had been tried and proved over many years of steel shipbuilding experience, there would surely have been an increased number of casualties resulting from the conditions under which the ships were required to be built and the more severe conditions under which they of necessity had to be operated. On the other hand, there are benefits resulting from having had to plunge these ships into such arduous tests in that the larger number of casualties resulting therefrom have afforded the opportunity of more comprehensive study to the end of pointing the way to improvements to insure greater margins against the extraordinarily severe conditions which might require to be met in peacetime even if only very infrequently. One cannot completely ignore the casualties which occurred where, by no stretch of the imagination, could extra severe conditions of wartime operation be said to be a contributing factor, such as those that occurred at the builders' docks, while in port, or since the war and in particular during the past winter, during which even though sea conditions were unusually severe, they could hardly be said to be a "wartime" condition.

DESIGN

It was in the field of design that opportunity was had during the construction program to take the most positive steps toward improving the performance of these welded ships. When casualties to Liberty ships were first receiving great publicity it was believed by many that sacrifices had been made in the structural strength of the ships' hulls in the interests of conserving steel and with the idea that the ships were to be considered as wartime expendables. Stories were rife as to the light construction of these ships, in some cases referring to them as "tin-cans." These beliefs and stories were entirely without foundation.

When the Maritime Commission was confronted with the necessity of establishing new shipyards and constructing large quantities of ships under the emergency program there was a great division of opinion as to the type of ship to be built. There had been developed in Great Britain a popular type of general utility vessel and contracts were under way for the building of a large number of vessels of this type, primarily riveted, in the shipyards in Canada. When arrangements were made to have 60 vessels of substantially the same general characteristics built in the United States, it was decided that the two new yards which were to be created for this purpose would be

planned for the construction of primarily welded ships and the plans which were developed for this program generally followed those for the riveted prototypes, merely being changed to substitute welding for riveting. These ships (later designated as the "Ocean" type) were designed to the then existing standards of Lloyd's Register for a draft of 18 in. in excess of that which could be obtained as a shelter deck vessel. The authorities in the United States finally agreed that vessels of substantially the same general characteristics should be adopted for the large-scale production of emergency ships of the so-called "work-horse" type (later designated "Liberty" ships). It was originally intended to keep the two types of vessels as nearly alike as possible so as to facilitate a central procurement plan particularly for forgings, castings, rudders, etc., so that these could be ordered out from subcontractors' plants as the need arose in the different shipyards participating in these two programs. However, it was decided that in order to meet production facilities in the United States and to make the vessels more suitable for United States operation, the boilers of the Liberty ships were to be changed from the scotch type to the watertube type and they were to be oil fired instead of coal fired. These changes entailed a considerable rearrangement of the ships so that opportunity was taken to redesign the hull. The open shelter deck features were eliminated and the vessels were redesigned on the full scantling basis with the scantlings all strictly in accordance with the Rules of the American Bureau of Shipping, with which these vessels were to be classed, at the deeper draft permitted.

In the case of the T2 tankers concerning which there were also a number of weird rumors, the structural scantlings for these vessels were all strictly in accordance with the Rules of the American Bureau of Shipping. The structural design was patterned after a group of ships which had been designed on a commercial contract by one of the established shipyards specializing in the construction of tankers, the only changes being made were a slight increase in depth to permit the use of flat sheer through amidships and still obtain approximately the same draft.

All of the other types of ships which had been contracted for on the long range program, and for which contracts were being extended, had been designed to meet the full requirements of the Rules of the American Bureau at the drafts for which the ships were designed.

Even before the war-emergency period, when the planning for large welded ships was first getting under way, the American Bureau had been under considerable pressure from the strong proponents of welding, to permit reductions in the thickness of shell and deck plating, based upon the superior efficiency of end connections and the absence of the complete rings of closely spaced rivet holes as occur at the bulkheads with riveted construction. With the advent of the war this pressure was vigorously renewed not only by the scientific people but also by those in charge of material allocations in an effort to obtain a further spread of the already overtaxed steel-producing facilities of the United States. Fortunately, this pressure was successfully resisted and it can truthfully be said that all of the welded merchant ships involved in the service records which are being made the subject of so much discussion at the present time have scantlings contributing to the over all longitudinal strength equal to those which would have been provided in riveted ships with no allowances made for superior end connections or the absence of rivet holes.

One of the first steps taken by the Board of Investigation was to re-examine all of the designs and the foregoing statements were completely substantiated. It was felt, however, that there was a possibility of a difference in the over-all behavior between riveted and welded construction and static bending tests were authorized to be carried out and a number of such tests were completed on several different types of vessels. These and a number of other tests which have also been completed in the United Kingdom on directly comparable ships of riveted and welded construction have merely demonstrated that in so far as observed stresses and deflections from applied loads are concerned, the theoretical principles by which the strength of a ship's hull girder is computed are equally applicable to riveted and welded construction.

A ship's hull is a unique structure in the engineering field in respect that it relies upon the heavy plate skin of the structure, formed by the shell and the strength deck plating, to resist the major forces to which it is subjected in service, the framing being of only secondary importance and being designed primarily only to hold the skin up to its work. In order that a ship can efficiently perform the service for which it is intended it is necessary to introduce into the main girder numerous openings, to add internal structure for tank divisions, machinery foundations, etc., and to add external appendages such as bilge keels, or bulwarks as well as superstructures or deck houses for the accommodation of crew, navigating equipment, etc. At the terminals of all of these openings, internal structure or appendages there are introduced structural discontinuities prohibiting uniform straining of the material under the major bending forces and resulting in stress concentrations. In addition, the ship's structure is subjected to many other secondary forces such as those creating torsion when operating in quartering seas, the slamming of heavy seas and those resulting from liquid contents in tanks, thrust from machinery, etc. Through many years of experience with riveted ships, designers have learned generally where they may expect troubles to develop and proper precautions against these have become more or less standard practice. In riveted ships the troubles usually evidence themselves in the form of loosened rivets rather than a fracture in the plate material as in the welded structures. Many items which experience had shown could be treated casually in riveted construction now require very careful attention as to detail when applied to the welded structure.

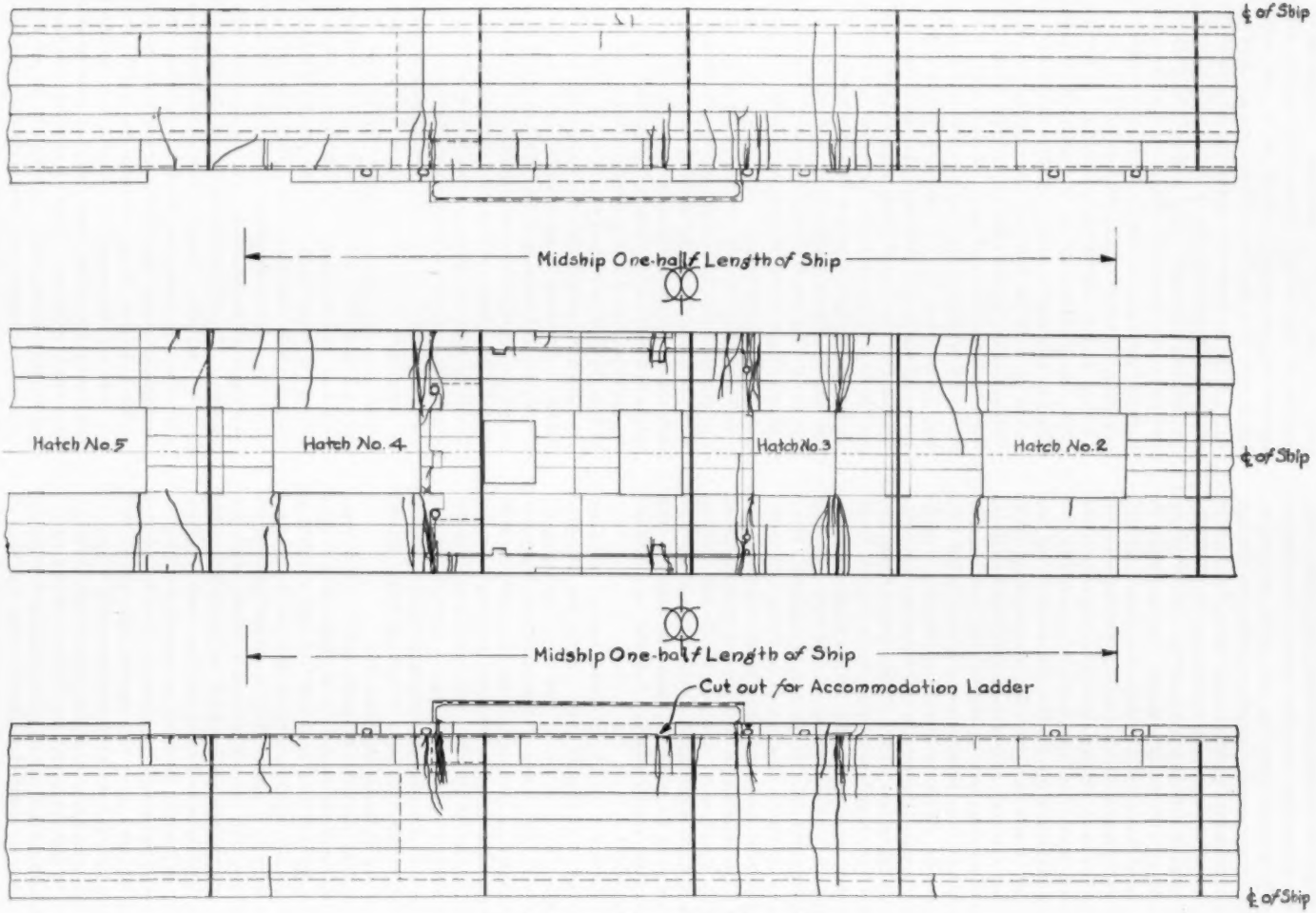

Fig. 1 Pattern of fractures in Liberty ships

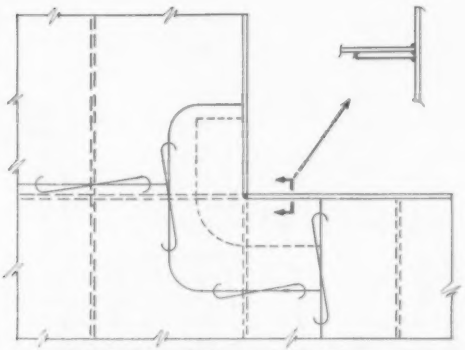

Fig. 2 Original Liberty ship hatch corner

When reports of casualties in Liberty ships were first beginning to accumulate, there began to be evident a somewhat pronounced pattern which indicated the culpability of certain of the details in initiating the fractures (Fig. 1). Outstanding among these which had resulted in casualties of the Group I classification were the corners of the Nos. 3 and 4 hatches, and a cutout which had been made in the top of the sheer strake for the installation of an accommodation ladder. To a lesser extent fractures of varying degree had been found to have apparently originated in bulwark rails, bilge keels, the corners of deck houses and at some ventilator openings near the corners of the deck houses.

Immediately these conditions became evident, action was taken to make corrections to the details at fault and as the program progressed directives were issued from time to time to put certain changes into effect. The original square-cut design for the midship hatch corners (Fig. 2) was modified to include a large radius in the plating, this being accomplished in several ways, one of which is shown in Fig. 3. In the ships for which the construction had progressed to such a degree as to make hatch corner changes impracticable, heavy internal reinforcing brackets were required to be installed (Fig. 4). The square cutout for the accommodation ladder was required to be modified (Fig. 5) and in later

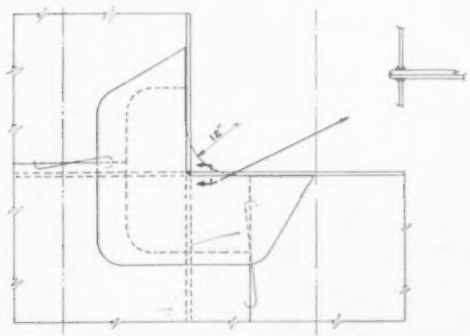

Fig. 3 Improved Liberty ship hatch corner

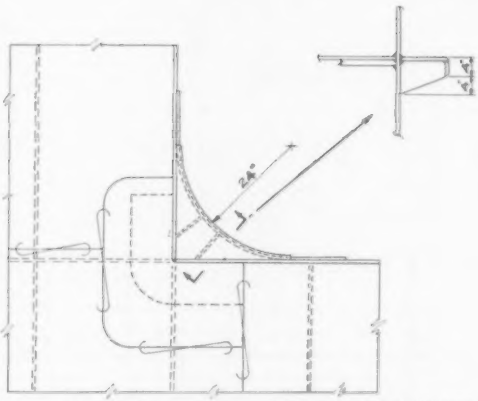

Fig. 4 Reinforcing brackets added to original Liberty ship hatch corner

ships the design of the ladder platform was modified to eliminate the necessity for these cutouts. Bulwarks were redesigned so as to provide attachment to the sheer strake only at widely spaced intervals and cutouts were required to be made in the bilge keels in way of butts (Fig. 6). At the same time these alterations were being made to the Liberty ships, a careful review was made of all of the other types of ships building and where corresponding conditions existed, corresponding alterations were directed.

The number of casualties in the Liberty ships, the causes for which could apparently be traced to these particular details, was felt to be of such proportion that it was decided to make similar alterations to all of the existing vessels of this type and through joint action by the American Bureau of Shipping, the U. S. Coast Guard and the Maritime Commission such directives were issued.

One must realize, however, that once agreement was reached that some alterations should be made, it was impossible to have these carried out except over a long period of time in view of the large number of ships involved. In the case of the ships under construction it

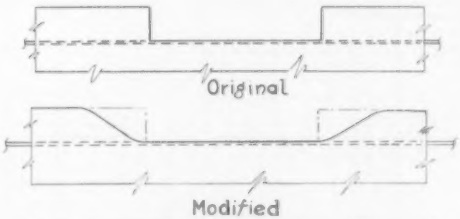

Fig. 5 Accommodation ladder cutout—Liberty ship

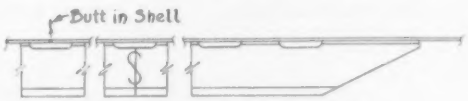

Fig. 6 Liberty ship bilge keel

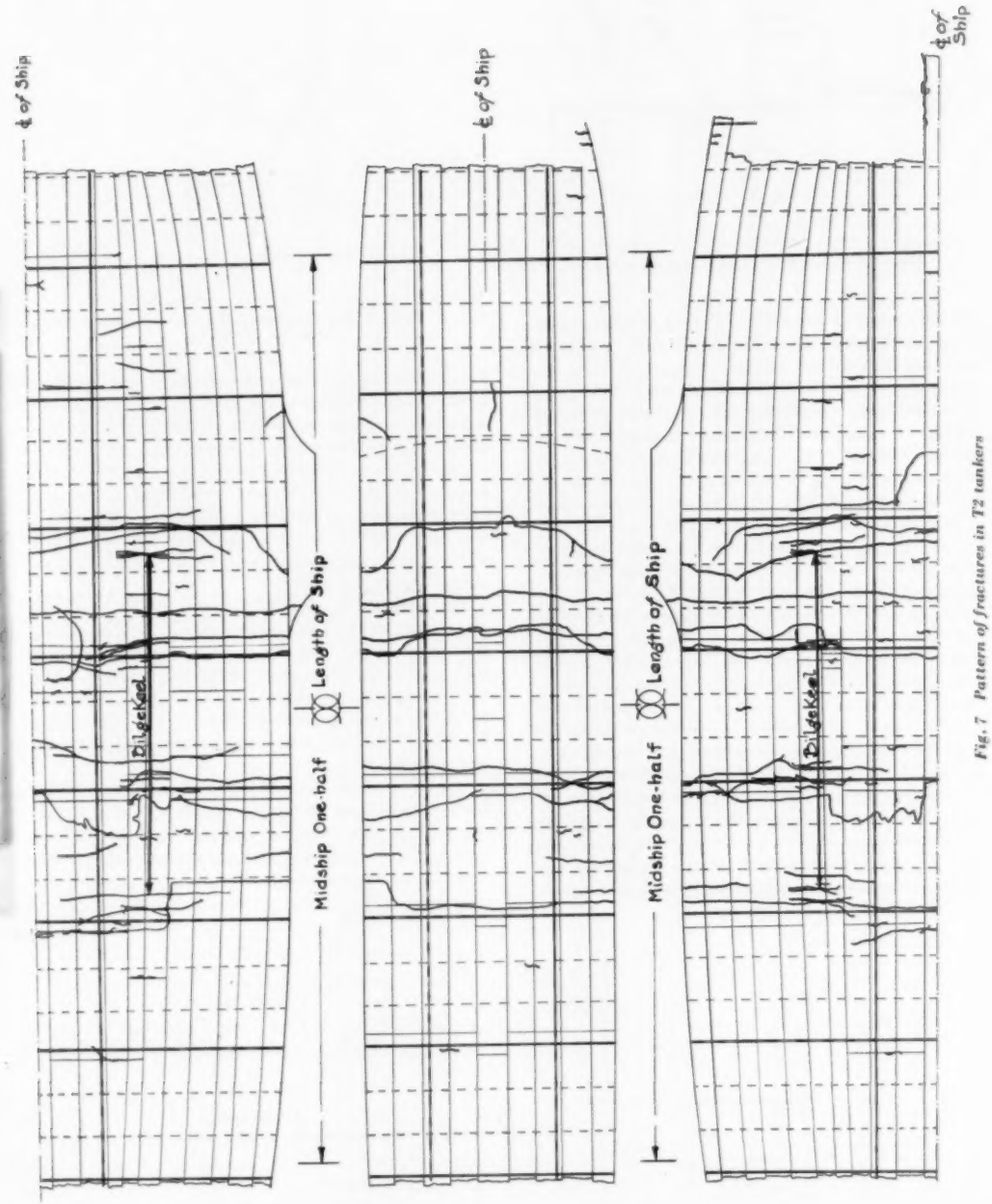

Fig. 7 Pattern of fractures in T2 tankers

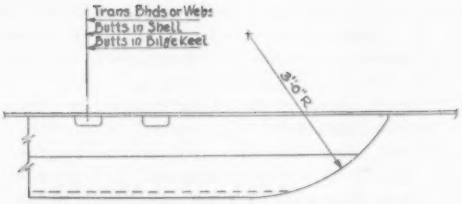

Fig. 8 T2 tanker—original bilge keel

was generally impossible to have the changes in effect until many ships later. The large-scale production of material required for this construction program and the great rate at which fabrication of material and the construction of large preassembled units preceded the actual keel layings, coupled with the fact that changes were authorized on a "not to delay" basis, made it extremely difficult to put into effect even only minor changes in details. As a result there were actually completed and placed in service over 1400 Liberty ships which accumulated 2430 ship-years of service record with the original details. This service record, even though it comprises only a small proportion of the total service record of over 13,400 ship-years of service of Liberty ships in class with the American Bureau, nevertheless is a very imposing figure and one which has proved to be of great value in assessing the importance of careful attention to design details in the all-welded ships.

In the case of the T2 tankers which were beginning to be placed in operation in large numbers in 1943, there were being received reports of Group I and Group II casualties of disturbing nature and steps were immediately taken to catalog and analyze these casualties in the same manner as was being done for Liberty ships and other groups of vessels. Unfortunately, the fractures reported did not appear to fall into any such pattern as did those in the Liberty ships and which pointed to definite improvements which could be made in design details (See Figs. 1 and 7). However, there was evident a quite pronounced grouping at the ends of the bilge keels and steps were immediately taken to modify the bilge keel endings (Fig. 8 and 9). In later

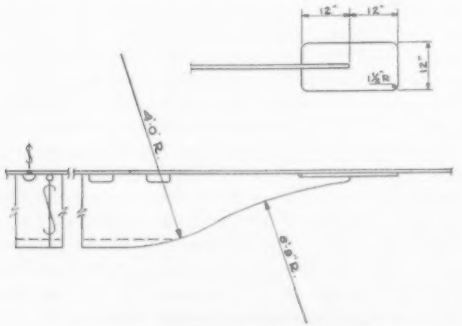

Fig. 9 T2 tanker—modified bilge keel

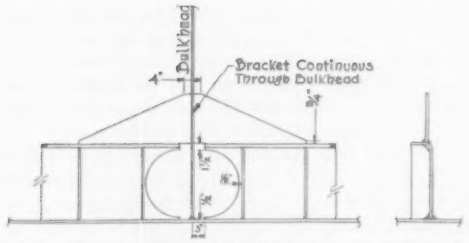

Fig 10. Connections of longitudinal frames at bulkheads

years there have been some fractures which are indicated as having had their inception just under the end of a bottom or bilge longitudinal adjacent to a transverse bulkhead and it has now become quite common practice where the heavy through bracket type of connection is used to introduce a large semicircular cut-out in the end of the longitudinal in an effort to relieve the hard spot and heavy stress concentration which is believed to exist at the longitudinal ending (Fig. 10). Apart from these two items, the records of the Groups I and II casualties in the large all-welded tankers have failed to provide any definite indications of necessary changes in design details.

In 1942 it was becoming apparent that through the emphasis being placed on standardization there were being acquired a too great a preponderance of the slow work-horse type Liberty ship and it was decided to develop a new, faster type of ship and put it into production in certain selected yards which had been building the Liberty ships. All of the experience which had been acquired in the construction and operation of the Liberty ships was brought to bear in the planning of this new type which was designated the Victory ship. The structure was arranged so as to lend itself readily to the prefabrication of large subassemblies up to the capacity of the handling equipment in the shipyards and careful attention was paid to the locations of the field joints so as to avoid critical locations and to provide the greatest accessibility for welding. Details which had proved to be troublesome in the Liberty ships were carefully redesigned. As an example it was de-

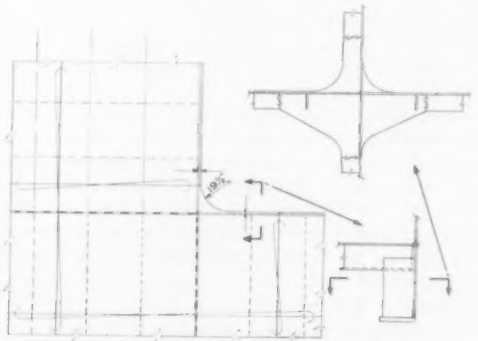

Fig. 11 Layout of Victory ship hatch corner

cided that the hatch corners should be cut with a large radius and that the use of doublers or insert plates should be avoided. The widths of plates available for these new ships were known and the width for the hatches was established so that an increase in the thickness of the plating at the corners was provided by the use of a heavier single plate comprising the full width of the plating strake (Fig. 11). It might properly be said that these ships were the first large cargo ships designed exclusively for welding, taking into account the facilities of the yards in which they were to be built, and available widths of plating strakes. Shortly after, a group of smaller ships 321 ft long and designated as the C1-M type were designed following somewhat similar planning.

Prior to the development of plans for these vessels, concern had been felt over the number of fractures originating in the upper parts of the Liberty ship hulls, three of which had resulted in complete failure of the hull and four of which had resulted in abandonment of the vessels. Directives had been issued calling for the fitting of a riveted seam strap just outboard of the line of the hatches and for a riveted gunwale connection at the Upper Deck throughout amidships, on all of the Liberty ships under construction where the alterations could be made without delay. Subsequently orders were issued requiring the installation in existing ships of a riveted connection either by cutting the stringer plate clear of the sheer strake or by cutting a slot in the sheet strake plate covering same with a double riveted strap. In realization of the possible benefits of these so-called crack arrestors it was decided to incorporate riveted gunwale angles into the original design of the Victory and C1-M ships.

These ships have performed excellent service, 414 of the Victory ships having amassed a service record of 2450 ship-years while in class with the American Bureau with only 12 casualties of Group II having been reported. Up until November 1951 there had been no casualties of Group I reported but during the fall and and winter of 1951–52 there were reported four such casualties. One of these was most unusual having consisted of a long fracture extending generally fore and aft in the bottom shell and was not of the transverse type generally found and which is causing concern for the structural integrity of the welded ships. Another has been quite definitely established as having resulted from a severe mishandling of the vessel in heavy seas. The third was indicated as having had its inception at a deck fitting which in the original construction had been extended through a slot in the deck and welded to framing, but which subsequently had been burned off flush with the deck. Very little is known about the fourth casualty since the vessel and all hands were lost. According to reports prior to the abandonment of the vessel, the fracture extended vertically in the side shell plating in the engine room for about 16 ft, but the reports give strong indications that the loss of the vessel was not occasioned by this crack but rather more from other causes. The C1-M vessels accumulated a service record of 1020 ship-years with only two casualties reported. Both of these are classed as Group I, extending completely across the deck on one side at about the middle of the length of a hatch opening.

These records are worthy of particular notice when it is considered that these ships were built under wartime conditions, using materials no better than those provided for the Liberty ship program. It is true that they came along late in the war construction program and that the concentrated educational campaigns as well as the great publicity given to the possible disastrous results of poor workmanship may have been beginning to have effect in improving workmanship. Likewise a larger proportion of the service record for these vessels was acquired after the war than is the case with the Liberty ships. Notwithstanding these favorable factors, however, it is felt that the service records of these two classes of ships are an indication of what can be done by careful designing and planning, taking full advantage of the lessons learned from previous experience.

EFFECT OF RIVETING

To just what extent the fitting of the riveted gunwale connections contributed to the improvement of the service record of these ships as compared to the Liberty ships is one on which we can only speculate. When the service records of the Liberty ships were first being accumulated, it soon became apparent that the ships built by the Bethlehem-Fairfield yard with riveted shell seams were showing a vastly superior record in so far as hull fractures were concerned. These ships were identical in design to the all-welded Liberty ships having completely welded Upper Decks with welded gunwale connections, the same square hatch corner details, etc., and it was not that the riveted seams stopped the cracks from spreading but the cracks themselves just did not occur with the same frequency. This early noticeable trend has continued throughout the continually increasing service records, and it appears that these ships built with the riveted seams are less susceptible to fractures originating from defective welds, poorly designed details, etc. When the studies of casualty records were beginning to show a need for improvement in some of the design details, the changes requested to be made to hatch corners, sheer strake cutouts, and bilge keels were made equally applicable to the Bethlehem-Fairfield ships and when these alterations were made retroactive to be applied to the existing ships, the Bethlehem-Fairfield ships were also included. The fitting of crack arrestors on the existing ships of this type was not required but a few of the last ships under construction were fitted with the strap on the deck just outboard of the line of the hatches and with a riveted gunwale angle. However, this was done on only a very few of these ships and it is impossible to establish whether or not this one change on the relatively few ships involved has had any influence.

Accordingly, for statistical purposes it has been

Table 1

Number of Casualties and Length of Service up to March 31st 1952 for Vessels over 300 ft in Length Built to Classification with the American Bureau of Shipping from 1938 until the Adoption of New Steel Specifications (1948) (Note 5)

Line Number	Type of Vessel	Length (Approx)	Amount of Riveting	All-Welded Ships: Number of Ships comprising Service Rec.	All-Welded Ships: Length of Service Record (Ship Years)	All-Welded Ships: Number of Casualties Group I	All-Welded Ships: Number of Casualties Group II	All-Welded Ships: Total No of Casualties Group I and II	All-Welded Ships: No of Cas Gr I & II per 100 Ship years	Ships with some Riveting: Number of Ships comprising Service Rec.	Ships with some Riveting: Length of Service Record (Ship Years)	Ships with some Riveting: Number of Casualties Group I	Ships with some Riveting: Number of Casualties Group II	Ships with some Riveting: Total No of Casualties Group I + II	Ships with some Riveting: No of Cas Gr I & II per 100 Ship years	Line Number
1	Liberty Ships with Original details	417'8	None (1)	1228	2100	88	328	408	19.45							1
2	with Improved details		None (1)	1890	2600	14	80	94	3.62							2
3	with Improved details		Gunwale Connection (2)							1057	4435	21	91	112	2.51	3
4	with Improved details		Gunwale Connection (3)							497	2258	18	50	68	3.01	4
5	with Original details		All Shell Seams							208	330	1	16	17	5.15	5
6	with Improved details		All Shell Seams (3)							313	1713	2	42	44	2.57	6
7	Victory Ships	436'6	Gunwale Angle							416	2458	4	12	16	0.65	7
8	C1-M Ships	321'4	Gunwale Angle							218	1020	2	0	2	0.20	8
9	Cargo & Passenger Vessels	365'	Side Shell Seams & Gunwale							9	41	0	0	0	0	9
10		390'	None	46	190	1	9	9	4.74							10
11		390'	All Shell Seams							19	109	0	8	8	7.35	11
12		395'	None	10	70	0	6	6	8.58							12
13		395'	All Shell Seams							85	462	5	21	26	5.62	13
14		400'	All Shell & Deck Seams							4	41	0	2	2	4.88	14
15		425'	Gunwale Angle							14	59	0	0	0	0	15
16		425'	Side Shell Seams & Gunwale							6	20	0	0	0	0	16
17		427'	None	3	29	1	1	2	6.90							17
18		431'	Gunwale Angle							6	41	0	0	0	0	18
19		431'	Side Shell Seams & Gunwale							3	12	0	0	0	0	19
20		435'	None	117	589	2	5	7	1.19							20
21		435'	Side Shell Seams							64	470	3	5	8	1.67	21
22		435'	All Shell Seams							33	298	0	14	14	4.70	22
23		445'	None	30	67	2	4	6	8.93							23
24		445'	Gunwale Connection & DK Strap							134	96	2	5	7	7.28	24
25		445'	Gunwale Angle & Hatch Coaming							9	60	0	2	2	3.33	25
26		450'	All Shell Seams							21	184	0	1	1	0.54	26
27		465'	None	138	760	6	40	46	6.79							27
28		465'	Gunwale Connection							3	16	0	0	0	0	28
29		465'	Side Shell Seams							5	41	0	0	0	0	29
30		465'	Side Shell Seams & Gunwale							11	65	0	0	0	0	30
31		465'	All Shell Seams							19	164	1	1	2	1.22	31
32		465'	All Shell & DK Seams & Gunwale							9	89	0	0	0	0	32
33		496'7	None	44	218	1	8	9	4.13							33
34		496'7	Riveted Gunwale							31	152	1	1	2	1.32	34
35		523'	Side Shell Seams							11	82	0	0	0	0	35
36		523'	All Shell Seams							10	71	0	0	0	0	36
37	Sub Totals for Cargo or Cargo & Pass Vessels		All-welded Ships	3498	6823	115	472	587	8.60							37
38			Ships with Riveting Added							1072	4531	23	96	119	2.62	38
39			Ships built with some Riveting							2021	10252	29	175	204	1.99	39
40	T-2 Tankers	503'	None	502	1933	29	69	97	6.53							40
41			Riveted Straps or Girders							492 (Note 4)	1772	21	43	64	3.61	41
42	T-1-M Tankers	309'	None	69	117	1	0	1	0.85							42
43			Riveted Straps							3	8	0	0	0	0	43
44		450	None	2	18	1	0	1	5.55							44
45		450	Side Shell & Deck Seams							4	41	0	0	0	0	45
46		487	All Shell & Deck Seams							5	38	0	1	1	2.63	46
47		487	Side Shell & Deck Seams							34	214	0	1	1	0.47	47
48		500	None	8	50	0	6	6	12.00							48
49		500	Side Shell & Deck Seams							14	135	2	7	9	6.67	49
50		505	All Shell & Deck Seams							4	22	0	0	0	0	50
51		505	Side Shell & Deck Seams							2	20	0	0	0	0	51
52		521	None	23	149	3	8	11	7.38							52
53		521	4 or 8 Riveted Straps							12 (Note 4)	57	1	8	9	15.80	53
54		525	All Shell & Deck Seams							31	276	0	4	4	1.45	54
55		541	None	5	31	0	2	2	6.94							55
56	Sub-Total for Tankers		All-welded Ships	569	1898	33	85	118	6.39							56
57			Ships with Riveting Added							505	1837	22	51	73	3.98	57
58			Ships built with some Riveting							94	759	2	13	15	2.01	58
59	Grand Totals		All-welded Ships	4067	8671	148	557	705	8.13							59
60			Ships with Riveting Added							1577	6368	45	147	192	3.01	60
61			Ships built with some Riveting							2115	10990	31	188	219	1.99	61

Note 1 In some cases frames were riveted but in all other respects vessels were entirely welded

Note 2 In some cases vessels also had a riveted seam strap in upper deck

Note 3 In some cases vessels also had a riveted gunwale angle and a riveted seam strap in upper deck

Note 4 The riveting in these vessels was added after the vessels had had some service as all welded vessels

Note 5 In this Table there have been excluded two small groups of special refrigerated type vessels

assumed that the Liberty ships can roughly be divided into six broad classifications as indicated by lines (1) to (6) in Table I. This table has been compiled to show the service records of all of the different types of oceangoing merchant ships built to class with the American Bureau of Shipping in quantities since just prior to the war and in which welding was used to any great extent. However, there have been omitted the records of two comparatively small groups of refrigerated cargo ships since it is generally accepted that a number of the casualties reported in these ships resulted from the abnormally low temperatures to which the steel was subjected. For purposes of comparison the figures for the all-welded ships have been set apart from those for the ships with some riveted longitudinal joints and in the latter cases the number of such joints has been indicated. There is no differentiation as to the method of attaching vertical side frames; ships which have riveted side frames but which are otherwise all-welded are classified as being all-welded. In the table are given the number of ships of each group contributing to the service record and the number of ship-years comprising the record. It should be noted that in some types the same ship may have contributed to the service record of more than one group owing to the classification as to type having been changed. For instance, an all-welded Liberty ship which commenced service with original details, then later had the improvements made and still later had riveted crack arrestors installed will appear in the count of 1220, 1890 and 1057 ships contributing to the service records of each of the first three types of ships listed, but only that length of time at which she was operated in the respective condition is included in the ship-year count. Since all of the all-welded Liberty ships with original details and all of the riveted seam Liberty ships with original details in class with the American Bureau have had improved details there are no longer being accumulated any additional service records for these two types and the figures given are final. With very few exceptions all of the all-welded Liberty ships with improved details have had riveted crack arrestors fitted so that the figures for this type are very near to being final. All of the T2 tankers in class with the Bureau have had at least four riveted crack arrestors since 1948 so that the figures for the all-welded T2 tankers became final at that time.

A study of the figures contained in this table can lead to many interesting speculations but it is not the author's intention to draw any positive conclusions but only to make available the facts as they have been accumulated in the records of the American Bureau of Shipping. It is realized that statistical tables can be very misleading particularly if one has not been sufficiently closely associated with their development to fully appreciate their limitations. However, analysis of the figures for the Liberty ship groups certainly appears to bear out the trends which were noticed early in the accumulation of service records concerning the probable beneficial effects of the riveted seams. It should be noted that in 2100 ship-years of service there occurred in the all-welded Liberty ships with original details 408 casualties of Group I and Group II type, a rate of 19.45 such casualties per 100 ship-years. For the Bethlehem-Fairfield ships, practically identical except for the riveted shell seams, there occurred 17 such casualties in 330 ship-years of service, a rate of only 5.15 per 100 ship-years. It should also be observed that of the 408 casualties in the all-welded ships, 88 or more than one in five included fractures which had propagated to such an extent that the casualty was classified as Group I, whereas in the ships with the riveted seams only one out of 17 included a really serious fracture. Worthy of note is the fact that by improving the details in the all-welded vessels the rate of occurrence of casualties was reduced from 19.45 to 3.62 casualties per 100 ship-years of service, a rate of reduction of better than 5 to 1 whereas in the ships with riveted seams the rate was reduced from 5.15 to 2.57 just 2 to 1, which appears to indicate the greater susceptibility to poorly designed details in the all-welded ships. In these two types of ships with the improved details the probability of fractures propagating to a dangerous degree in the ships with riveted seams still appears to be decidedly less than in the all-welded ship. It might readily be expected that fractures in the shell where the seams are all riveted would be limited in extent but the majority of the casualties reported in both types of ships comprised fractures in the Upper Deck where the riveted seams were not present.

It is possible that these service records may have been influenced to some extent by the fact that all of the Liberty ships with riveted seams were built in only one yard and that in that particular yard nearly all of the plate material came from one supplier. An investigation which was made by a special welding advisory group during the course of the construction program, and which covered all phases of the shipyard organizations, procedures and practices affecting the quality of workmanship in all of the yards participating in the program, failed to disclose any pronounced superiority in the Bethlehem-Fairfield yard and such investigations of the quality of the steel supplied to that yard as have been made have likewise failed to support any belief that the steel used was in any way superior to that being supplied to the other yards building Liberty ships. When the superior service records of these ships with the riveted seams first became apparent, it became the practice to assign them to the more arduous service routes so that if there is any influence whatever, resulting from trade routes, such influence should properly be expected to be against these ships.

It is perhaps unfortunate that we do not have any other large groups of ships which are directly comparable, except for some riveted connections, and which have compiled a sufficiently large service record to be of statistical value. It is true that the service records for the all-welded Liberty ships with improved details and those for the T2 tankers show some im-

provement after these two types were fitted with riveted crack arrestors, but since the large bulk of the Liberty ships and all of the T2 tankers comprising these groups had several years of operation under wartime conditions before the arrestors were fitted it can reasonably be expected that poor workmanship might have disclosed itself in the form of casualties and that the correction of the more serious defects as disclosed, coupled with what is believed to be the less arduous services in peacetime, would have resulted in some improvement in the service records even if the arrestors had not been fitted.

Just prior to and during the war years and for a few years immediately following the war there were built in the shipyards of the United States 67 all-welded seagoing tankers of over 300 ft in length in addition to the T2 tankers. There were also built 94 large tankers in which welding had been used extensively but in which riveting had been used in varying degrees. While not duplicates of the T2 tankers, all of these vessels have marked similarity. They are all longitudinally framed and include details corresponding to those which have been under suspicion as having contributed to some of the casualties in the T2 tankers. A number of these vessels have plate and angle bulkheads instead of the corrugated bulkheads as fitted in the T2 tankers, but there is no evidence whatever that the type of bulkhead construction has any influence on the creation of fractures comprising a Group I or Group II casualty. A large proportion of these vessels was built under the pressure of wartime urgency and for all of these vessels the hull steel supplied was of no better quality than that used in the T2 tankers. The service records for the 67 all-welded tankers combined with those of the T2 tankers prior to being fitted with riveted straps are given in line 56 of the table. The records for the 94 vessels which had been built with some riveting are given in line 58 and we find very much the same pattern of relatively superior service records as is shown by the Liberty ships having riveted shell seams. It is interesting to note that of the 15 casualties reported in the tankers built with riveting, 12 of these involved fractures in butt welds where workmanship was clearly at fault, there being no suspicion of a design detail having contributed to the casualty. The details of the remaining three casualties have never been clearly established.

These data appear to support statements which have been made in the past by a number of experts in the shipbuilding field to the effect that, in the light of our present knowledge as to the fundamental causes of fracture in welded ships' hulls, a judicious mixture of welding and riveting may be the most sound approach. There are many who deplore the now almost universal practice of including several riveted longitudinal connections in the shell and decks of the modern large otherwise all-welded ships. These joints are often termed crack-stoppers and they are often referred to as representing a defeatist attitude on the part of shipbuilders, it being claimed that all efforts should be directed toward preventing cracks from initiating to the end that it should not be necessary to provide these joints to limit their extent. The author can have no quarrel whatever with this philosophy but it is quite possible that the inclusion, in the original construction, of a number of riveted longitudinal connections may, in addition to providing a means to stop a crack, once started, also have some beneficial effect on the liability of the starting of a crack. There are some who maintain that the punching or drilling of holes for rivets near the edges of plates or in a heavy riveted gunwale angle seriously weakens these members at important locations. There is no doubt that these holes do detract from the strength in tension but in all of the service records of ships built with riveted seams or gunwales, there have never been any indications that this weakening has been the cause of a failure.

WORKMANSHIP

It is almost impossible to separate design from workmanship since these two phases of the problems with which we are confronted are inextricably related. In nearly every case where design details have been considered to be a contributing factor in the initiation of a fracture, the question of workmanship has also been involved. The original square-cut design of the hatch corners in the Liberty ships, while admittedly not the most desirable design, probably would not have caused so many fractures had the workmanship been of the highest quality in every case. Generally, in the examination of those fractures which have apparently had their inception at discontinuities such as occur at the ends of bilge keels, the ends of longitudinal frames adjacent to bulkheads in tankers or at the connections of fittings or fashion plates to the sheer strakes, it has been found that the workmanship is of very doubtful quality, the welding often being found to be improperly fused or accompanied by deep undercutting. Designers can, to a certain extent, develop design details in which the susceptibility to poor workmanship can be reduced but there is still a great dependency on the quality of workmanship in order that there may be produced a completely trouble-free structure. In the Liberty ships alone out of a total of 735 casualties reported, 132 or approximately 18% were indicated as having had their inception in a defective weld in a butt or seam, where there was present no structural discontinuity or design detail which could possibly have contributed to the failure. In the T2 tankers over 50% of the casualties have had their origin in welds which are entirely clear of any discontinuities and in the tankers with some riveted seams this ratio is still higher.

It is most difficult to point to any positive measures which have been taken to insure none but the best welding. In general, shipyards have tightened up on the requirements for qualifying welders, there have been made available and put into general use improved methods of inspection such as X-ray or Gamma-ray

methods, but the latter admittedly can only be used as a spot-check measure, exploring only a few of the more critical areas, and their benefits depend to a large extent on the psychological effect on the individual welder.

During the war shipbuilding program, due to the tremendous expansion of the shipbuilding industry in the United States, the recruiting of a sufficient number of competent inspectors to serve the shipyards themselves, the owners, the government regulatory bodies and the Classification Societies to the same extent as is done in normal times was an impossible task. The practice of working the plants on an around-the-clock basis undoubtedly had an adverse effect on the quality of workmanship. The urgency with which the ships were required to be produced occasioned an attitude on the part of the few available inspectors toward being liberal in their judgment as to what should or should not be accepted. Coupled with the fact that many of the welders being employed had had little or no prior experience, it is not surprising that we should have uncovered so much defective workmanship, but it is confidently believed that we can and have profited by the lessons learned.

In the shipyards today, the supervision is far more extensive and more severe in judgment; many of the yards have elaborate positioning equipment and provide better working facilities, all of which should have a decided effect on the quality of workmanship, but we are still dependent to a great degree on the integrity of the individual welder to produce under working conditions the high quality welds which he has shown he can produce when passing the qualification tests. There is a great deal that needs to be done toward reducing this dependence on the individual and it is a challenge to the welding industry in general to continue to strive to make available to users improved equipment, electrodes, etc., which will make the production of good sound welds more or less automatic, to the end that even an indifferent welder will find it difficult to produce a poor weld. There are being brought into prominence new improved electrodes such as those of the lime-coated, low-hydrogen variety. These have shown great promise for certain applications, but opinion in American shipyards is still against their widespread adoption on account of questions regarding usability. It is all very well to demonstrate what a certain piece of equipment is capable of producing but what concerns those of us in the shipbuilding field, as well as those connected with the production of other large field-welded structures, is not so much what the equipment can do under controlled conditions but what it actually does do in actual service.

MATERIALS

It is in the field of materials where the most positive steps have been indicated as being practicable to undertake in an effort to guard against the repetition of the serious casualties which have occurred in the war-built vessels. As mentioned earlier in this paper, in the report presented by the committee of experts appointed by the American Bureau of Shipping to investigate the failure of the T2 tanker *Schenectady*, there was raised the question as to the adequacy of the then existing specifications for hull steel to provide proper materials for welded construction. There was no fault to be found with the steel involved in the fracture when compared with material which had always proved to be satisfactory for use in riveted ships and it was quite apparent that in the large welded structures there had been introduced conditions which made the notch toughness of the steel of far greater significance than had been the case in riveted construction. When the Board of Investigation of the Design and Methods of Construction of Welded Steel Merchant Vessels commenced to function, one of the early steps taken was the initiation of research projects on this subject. Vast sums of money were spent on projects in the various laboratories of Universities in the United States but no specific recommendations for a revision in specifications were produced. When the Board made its final report in 1946 a great deal of research in this and other fields had not been completed and some of the work in hand had already pointed to the need for continued study and the initiation of new projects. Accordingly, the Board recommended that an organization be set up to continue this work. Acting upon this recommendation, the Secretary of Treasury, to whom the functions of the Coast Guard had been restored at the close of the war, appointed a committee known as the Ship Structure Committee comprised of representatives from the same agencies as had been represented on the Board. Under the auspices of this committee a large amount of research work has been and still is being carried out aimed at the development of a new ship steel specification. Liaison has been maintained with corresponding groups working on the same subject in the United Kingdom and elsewhere and all of this work has been highly publicized and made available to those interested throughout the world. Concurrently with this research work, a program of investigation of steel removed from fractured ships was inaugurated under the direction of the Board and later the Ship Structure Committee, and at the same time we in the American Bureau undertook a paralleling program in our own laboratory. Under these two programs steel which had been involved in casualties on nearly 100 ships has been subjected to most exhaustive tests and there has been developed a rather well-defined pattern indicating that material where a fracture originates usually shows a relatively low notch toughness and a high transition temperature. Where a fracture terminates in parent metal, the material shows a relatively high degree of notch toughness with a low transition temperature, and material through which a crack propagates usually falls in between. Agreement has not yet been reached as to a proper test for specification purposes nor as to quantitative values related to any particular test, but in appreciation of the work which had been completed, the American Bureau of Shipping formed, in its organization of Technical

Committees, a Special Sub-Committee on Materials. Appointed to this committee were leading experts from steel manufacturers, shipbuilders and users of steel in other fields. All of the data available were carefully reviewed by this committee and, after a number of meetings, agreement was reached in 1947 to modify the Rules to include additional specifications for hull-steel plates which in the opinion of the committee would successfully screen out the more notch-sensitive steels.

Inasmuch as there never had been any record of failures in small ships, barges, etc., which did not require the use of heavy plates, or in structural shapes, and in recognition of the well-established fact that for steel plates rolled from any one heat, the transition temperature and notch sensitivity increase with an increase in thickness of the rolled material, it was decided that the specifications should be set up to cover three grades of steel.

The recommendations of this committee were reviewed by the Committee on Naval Architecture and later by the Main Technical Committee of the Bureau, and in November 1947 they were approved and officially made a part of the requirements for classification with the Bureau. In subsequent years some minor modifications have been made but the present specifications which are repeated in the following are substantially the same as those agreed upon in 1947.

Structural Steel for Hulls

Process of Manufacture: The steel used in the construction of the hulls of vessels shall be made by either or both the open-hearth or electric-furnace process.

Chemical Composition—Ladle Analysis: (*a*) Except as specified in paragraph (*b*) the material shall conform to the requirements of Class A as to chemical composition.

(*b*) Plates over 1/2 and up to 1 in., inclusive, in thickness shall conform to the requirements of Class B as to chemical composition. Plates over 1 in. in thickness shall conform to the requirements of Class C as to chemical composition.

	Class A	*Class B*	*Class C**
Carbon, max %	..	0.23	0.25
Manganese, %	..	0.60–0.90	0.60–0.90
Phosphorus, max %†	0.04	0.04	0.04
Sulfur, max %	0.05	0.05	0.05
Silicon, %	..	..	0.15–0.30

* Plate steels produced to the requirements of Class C shall be made with fine grain practice.

† Where steel is made by the acid process the maximum per cent phosphorus permitted may be 0.06.

Tensile Properties: (*a*) The material, except as specified in paragraph (*b*), shall conform to the following requirements as to tensile properties:

	Structural steel	*Rivet steel and steel for cold flanging*
Tensile strength, psi	58,000–71,000	55,000–65,000
Yield point, min psi	32,000	30,000
Elongation in 8 in., min %	21	23
Elongation in 2 in., min %	22	..

(*b*) Flat-rolled steel 3/16 in. and under in thickness, shapes less than 1 sq. in. in cross section, and bars, other than flats, less than 1/2 in. in thickness or diameter, need not be subjected to tension tests.

(*c*) For material over 3/4 in. in thickness or diameter, a deduction from the percentage of elongation in 8 in. specified in paragraph (*a*) of 0.25% shall be made for each increase of 1/32 in. of the specified thickness or diameter above 3/4 in. to a minimum of 18%.

(*d*) For material under 5/16 in. in thickness or diameter, a deduction from the percentage of elongation in 8 in. specified in paragraph (*a*) of 2% shall be made for each decrease of 1/32 in. of the specified thickness or diameter below 5/16 in.

Bending Properties: The bend-test specimen shall stand being bent cold through 180 deg without cracking on the outside of the bent portion to an inside diameter which shall have the following relation to the thickness of the specimen:

	Ratio of bend diameter to thickness of specimen	
Thickness of material	*Structural steel*	*Rivet steel and steel for cold flanging*
3/4 in. and under	1	Flat on itself
Over 3/4 to 1 1/4 in., inclusive	2	1
Over 1 1/4 in.	3	2

It should be noted that the specifications for Class A steel covering all shapes and plates not exceeding 1/2 in. in thickness do not differ materially from the specifications which were applicable to all hull steel during the war construction program. The specifications for Class B steel covering plates over 1/2 in. but not exceeding 1 in. in thickness, however, have been amplified to include a limit on carbon and a specified range for manganese while those for Class C, covering plates over 1 in. in thickness have, in addition, a silicon requirement and an added requirement that the steel shall be made with fine-grain practice such as will insure a fully killed fine-grain steel.

The reception which was accorded to these new specifications when they were first announced was most gratifying. At the time there were actually under contract or in the process of being contracted for in the United States shipyards a large number of tankers of 26,000 to 30,000 tons deadweight. These were to be primarily of welded construction having only a few riveted seams on each side and some of the owners and builders were still apprehensive of welded construction even with the few riveted seams. Even though these ships were under contract at fixed prices the builders and owners through mutual agreement adopted the new specifications and accepted the extra cost resulting therefrom so that for all of the vessels for which the heavy plates had not as yet been produced, steel in accordance with the new specifications was obtained. As a result there are now in operation more than 40 of these large tankers in class with the Bureau in which the improved steel was used. These have compiled only a relatively small service record totaling only a little over 80 ship-years but we have not as yet received a single report of a fracture comprising a Group I or Group II casualty.

The Bureau has never maintained that these specifications are the last word on the subject and it is recognized that some notch-sensitive material may still leak through. Research on this problem is still being pursued vigorously and a continuous program of random checking of material as actually being supplied to shipyards has not yet disclosed any particularly undesirable material furnished under the new specifications. It is probable that as the sizes of ships increase, involving the use of heavier material it may be found that the present specifications will require to be supplemented for the extremely thick plates by additional chemical controls or by heat treatment of the finished material.

The steel specifications adopted by the Bureau have received widespread recognition, and in a number of fields of welded structures other than shipbuilding, use has been made of these specifications in an effort to overcome difficulties which have been experienced in those fields. It is particularly worthy of note that in the years following this action taken by the American Bureau of Shipping, the other leading Classification Societies have taken similar action. In some cases the method of approach is somewhat different, but they have all aimed at the same objective, i.e., the obtaining of plates of good notch toughness at low temperatures. In some of the other Societies' Rules, the supplementary specifications are specifically mentioned as being applicable only to welded construction. There is no doubt but that the problem of notch toughness of plates was brought into prominence with the advent of welding and that previous specifications had proved adequate for riveted ships but the Committee of the American Bureau decided that welding was here to stay in the construction of ships, and that the problems of housekeeping would be almost impossible of solution if we were to have two specifications for steel, particularly in repair yards.

CLOSURE

This is not the type of paper which lends itself to a brief summary in the form of conclusions. It has been the author's intention to merely set forth the background of experience acquired with welded construction in the shipyards of the United States prior to the war construction program, the experience acquired during that program and with the ships built during that emergency period in the belief that many valuable lessons can be learned from that experience. We have learned that designers must continually strive toward the development of details which will lend themselves readily to good sound workmanship and that with welded construction careful attention must be paid to what might have been considered to be only a very inconsequential and most trivial detail in riveted construction. We have learned the important part that workmanship plays in the creation of the trouble-free welded structure. Any welds which are in any way under suspicion should be carefully explored and those of doubtful quality should be renewed. Careful fitting is a necessity since experience has demonstrated the possible disastrous results of excessive forcing of subassemblies or the use of excessive welding to make up extra wide welded joints. We must adopt steel specifications which will effectively screen out highly notch-sensitive material, and even though these may entail some added cost we must accept this added cost in the realization that it is justified by the protection gained against fractures.

One thing we must guard against is complacency. One often hears a certain owner or builder decry the emphasis which is being placed on design, workmanship and material, maintaining that he has never had any difficulties with any of the ships owned by him or built by him. After all, there have been only a comparatively small number of serious casualties in the welded ships when related to the vast numbers of such ships in service. There are several thousands which have given completely trouble-free service in so far as the hull structure is concerned but, unfortunately, it has never been possible to establish just what was done in the trouble-free ships and was not done in the ships which suffered casualties and vice versa.

The author can only state that he has the greatest confidence in the ability to safely employ this comparatively new and most desirable method of joining steel parts, provided we are all prepared to pay careful heed to the experience so far acquired. He is completely willing to subscribe to the opinion expressed in the report of the Board of Investigation of the Design and Methods of Construction of Welded Merchant Vessels and which has of late been repeated by several authorities, to the effect that with proper detail design, high quality workmanship and a steel which has low notch sensitivity at operating temperatures, a satisfactory all-welded ship structure may be obtained.

The Arc Welding of Low Chromium-Molybdenum Steel Pipe

Comparison of low-hydrogen and cellulose-coated electrodes in welding two types of low chromium-molybdenum steel pipe

by J. Bland, L. J. Privoznik and F. J. Winsor

Abstract

The arc welding of 0.5% Cr – 0.5% Mo steel pipe has been investigated, using conventional cellulose-titania and low-hydrogen alloy electrodes.

The results indicate that the static mechanical and impact properties of the low-hydrogen electrode welds, made using preheat and interpass temperatures of −60° F and ambient, and without postheat treatment, are equivalent or superior to those of the conventional cellulose-titania electrode welds, made using 500–600° F preheat and 1250° F for 1-hr postheat treatment.

The Charpy keyhole-notch transition temperatures of the low-hydrogen electrode welds were found to be below that of the as-received 0.5% Cr – 0.5% Mo steel pipe material. The low-hydrogen electrode weld metal transition temperature is raised by a postheat treatment at 1050° F for 8 hr; no transition temperature change, from that of the as-welded deposit, is produced by a postheat treatment at 1200° F for 16 hr. However, energy absorbed to fracture at room temperature is increased by the 1200° F postheat treatment.

Results of limited tests of low-hydrogen electrode welds in 1.25% Cr – 0.5% Mo steel pipe indicate satisfactory properties in the as-welded condition. Thermally treated welds (450° F preheat, 1350° F for ½-hr postheat) exhibit lower hardness and strength and higher ductility than in the as-welded condition, but the as-welded properties were entirely adequate.

INTRODUCTION

INDUSTRIAL progress, particularly in the steam power industry and in petroleum refining, has demanded the use of increasingly higher temperatures and pressures for process operations. Higher temperatures and pressures in the steam power industry mean increased efficiency and less cost per kilowatt-hour produced. Higher temperatures and pressures in the petroleum industry mean higher product yields as well as new products which cannot otherwise be produced.

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Initially, carbon – 0.5% Mo steel was used when operating temperatures began to exceed about 850° F, the limit beyond which plain carbon steel could not safely be employed for extended service at the pressures involved. The use of this steel for power piping was seriously questioned and ultimately restricted in the steam power industry as a result of the Springdale, Pa., failure in 1943, which was attributed to chain-type graphitization in the heat-affected zones of the welds and rupture under shock loading. The investigations of this failure and subsequently of the graphitization phenomenon have been covered adequately in the literature. The addition of 0.5 to 1% chromium to the carbon – 0.5% Mo steel appears to be effective in preventing graphitization, as indicated by Fitzgerald, Wilder, Smith and White,[1] who also reported on the room and elevated temperature properties of the 0.5% Cr – 0.5 % Mo alloy. The steam power industry has made extensive applications of this alloy for power piping, and with even higher temperature-pressure installations has begun to use the higher creep-strength and oxidation (scaling) resistant 1.25% Cr – 0.5 % Mo and 2.25% Cr – 1% Mo alloy steels.

The petroleum industry has experienced graphitization of process equipment steels only to a limited extent, and only in the form of randomly dispersed nodular graphite which, as yet, has not been proved to have any significant effect on the properties of the steel.[2] However, a somewhat different deterioration has been found in plain carbon steels of refinery process piping and equipment exposed to hydrogen-bearing gases at elevated temperatures and at high hydrogen partial pressures. This attack, known as high-temperature hydrogen embrittlement, produces fissuring and decarburization of the steel and frequently results in failure without warning. The low chromium-molybdenum steels are resistant to hydrogen embrittlement at high temperatures[3] due to the greater stability of the chromium-molybdenum carbides, compared with the iron carbide of plain carbon steel.

The original work on the 0.5% Cr – 0.5% Mo steel [1] included some results on the properties of welds made

Table 1—Chemical Composition of Alloy Base Materials

Material	Chemical composition, % C	Mn	P	S	Si	Cr	Mo
0.5% Cr – 0.5% Mo steel pipe	0.13	0.44	0.012	0.021	0.22	0.63	0.58
1.25% Cr – 0.5% Mo steel pipe	0.16	0.47	0.011	0.022	0.78	1.23	0.61

with specially developed AWS Type E7011 cellulosic electrodes. The welds, made from electrodes which deposited metal containing about 0.35% Cr and 0.5% Mo, were made using 500° F preheat and 1350° F postheat treatment. Holmberg[4] discussed the weldability of the ferritic chromium-molybdenum steels, particularly the 5 to 9% Cr – 0.5 to 1% Mo alloys, and the use of austenitic electrodes when postheating could not be effected. Navarre[5] reported on the weldability of the 0.5% Cr – 0.5% Mo alloy using 0.5% Cr – 0.5% Mo cellulosic electrodes with 300–400° F preheat and 1275–1300° F postheat treatments.

The important advances made in the formulation of electrode coverings in recent years have resulted in the development of ferritic chromium-molybdenum low-hydrogen electrodes whose weld deposits match the chemistry of the parent metals on which they are used. The investigation reported herein was begun in 1950 for the purpose of evaluating the properties of weldments made with these low-hydrogen type electrodes on low chromium-molybdenum alloy steel pipe. One of the major aspects of this work is to determine the extent to which thermal treatments are required in order to obtain satisfactory properties of the weldments.

The results reported below cover, for the most part, those obtained during the investigation of 0.5% Cr – 0.5% Mo steel. Results of limited tests of the 1.25% Cr – 0.5% Mo steel welds are also included in this paper.

EXPERIMENTAL PROCEDURE

The various test specimens used throughout this investigation were prepared from full thickness multipass butt welds made between 6-in. long pieces of the particular alloy pipe. The weld joints were either 60- or 75°-included angle single Vees, with a $^1/_{32}$- to $^1/_{16}$-in. root face and $^3/_{32}$- to $^1/_8$-in. root opening. No backing straps were employed in order to duplicate, as closely as possible, procedures typical of refinery piping fabrication. The various welding conditions used, as well as the preheat, interpass and postheat temperatures and holding times employed, are described in the several tables included below with the results. Most of the welds were made in the flat position (horizontal rolled), with some vertical and overhead positioning (horizontal fixed) to evaluate the out-of-position usability characteristics of the various electrodes. Welding currents in the range recommended by the manufacturers for the particular electrode brand were used. All specimens were tested at room temperature, except for those used in transition temperature studies.

MATERIALS

The two alloy materials employed for this investigation were a nominal 0.5% Cr – 0.5% Mo steel tube (to be referred to as pipe), 5-in. O.D. by 0.750-in. wall, ordered to ASTM Specification A280–48T, and a nominal 1.25% Cr – 0.5% Mo steel pipe, 5-in. nominal Schedule 160, conforming to the chemical requirements of ASTM Specification A200–51T, Grade 1. The chemical compositions of these alloys are shown in Table 1.

The electrodes used were designed to deposit weld metals with nominal compositions between 0.5% Cr – 0.5% Mo and 2.25% Cr – 1.0% Mo. All of the electrodes were low-hydrogen types with the exception of one brand which had a high titania-potassium (medium cellulose) covering. The chemical compositions of the weld metal deposits are listed in Table 2.

RESULTS

0.5% Cr – 0.5% Mo Steel

Tensile Tests of Flat Position Butt Welds. All reduced-section tensile test specimens of welded 0.5% Cr – 0.5% Mo steel pipe from which the reinforcement had been removed, failed in the parent metal (see Table 3), regardless of the electrode used or of whether or not preheat or postheat treatments were applied. The ultimate strengths obtained represent that of the parent

Table 2—Welding Electrodes and Chemical Composition of Deposited Weld Metals

Brand code	AWS classification	Covering type	Composition of weld metal, % C	Mn	P	S	Si	Cr	Mo	Nominal Cr-Mo
A	E8013	High titania-potassium	0.11	0.36	0.016	0.035	0.37	0.41	0.49	0.5 –0.5
B	E7015	Low-hydrogen-sodium	0.11	1.12	0.019	0.024	0.31	0.64	0.67	0.5 –0.5
C	E8015	Low-hydrogen-sodium	0.08	0.67	0.018	0.022	0.36	1.14	0.70	1.25–0.5
D	E8016	Low-hydrogen-potassium	0.08	0.43	0.023	0.025	0.33	1.02	0.56	1.0 –0.5
E	E9015	Low-hydrogen-sodium	0.07	0.74	0.014	0.028	0.24	2.57	1.40	2.25–1.0
F	E9015	Low-hydrogen-sodium	0.08	0.48	0.020	0.015	0.15	2.32	1.07	2.25–1.0

Table 3—Mechanical Properties of Flat Position Butt Welds in 0.5% Cr – 0.5% Mo Steel Pipe

Electrode brand	AWS type	Treatment of weldment	Tensile tests[a] Ultimate strength, psi.[b]	Tensile tests[a] Elongation, % Weld	Tensile tests[a] Elongation, % Total in 2 in.	Hardness tests[c] H. A. zone Avg	Hardness tests[c] H. A. zone Max	Hardness tests[c] Weld Avg	Hardness tests[c] Weld Max	Side-bend tests Passed	Side-bend tests Failed[d]	Side-bend tests Remarks	Free-bend tests; % Elongation in weld metal[e]
Code A	E8013	As-welded[f]	69,700	2.3	26.7	205	222	223	227	0	2	Broke in weld	8.5
		550° F preheat; 1250° F-1 hr stress relief	64,200	5.2	36.3	176	192	202	209	0	2	Broke in weld	15.0
Code B	E7015	−60° F prefreeze; as-welded	69,900	1.0	24.0	182	200	237	243	3	1	Unfused root; slag	...
		As-welded[f]	69,600	0.5	26.0	182	195	237	240	4	0	Slight root tear	4.3–8.0
		No preheat; 1050° F-8 hr stress relief	...	...	...	176	190	234	240	..	..	.....	...
		No preheat; 1200° F-16 hr stress relief	...	...	...	153	159	205	210	..	..	.....	...
Code C	E8015	−60° F prefreeze; as-welded	70,800	1.0	24.5	182	200	219	222	3	1	Slag in root	...
		As-welded[f]	70,700	3.5	26.5	170	180	200	202	4	0	Slight root tear	5.4–6.3
Code D	E8016	−60° F prefreeze; as-welded	70,000	1.0	25.0	180	203	219	222	4	0	.....	...
		As-welded[f]	70,800	2.5	27.0	167	169	202	205	3	1	Unfused root	...

[a] Reduced section tensile specimens—weld reinforcement removed. Results average of two specimens. All failures occurred in the parent metal.

[b] Parent metal—Ultimate strength, 67,000 psi; elongation, 55% in 2 in.

[c] Brinell hardness numbers converted from Rockwell hardness data. Parent metal, as-received—142 Brinell average.

[d] Specimens showing a crack or other defect exceeding 1/8 in. in length were considered to have failed.

[e] Approximately 0.7- to 0.8-in. gage length.

[f] Preheat and interpass temperature under 200° F. No postheat.

metal, and only the 1250° F for 1 hr heat treatment produced a significant reduction in this ultimate strength. In this connection it may be noted that the nominal yield strengths of the several brands of electrodes used are approximately equal to or higher than the ultimate strength of the parent metal.

The ductility of the welds was determined by measuring the elongation of the weld metal as well as by measuring the elongation of the full gage length which included both weld metal and parent metal. The results indicate that, in general, the as-welded low-hydrogen electrode weld metal exhibited slightly less elongation than did the cellulose-titania electrode weld metal, without postheat treatment in both instances. The elongations of as-welded, as well as of preheated and postheated, cellulose-titania electrode welds fell within the range of total elongation found for the low-hydrogen electrode welds. It should be pointed out that the low values of elongation measured in the weld metal do not necessarily reflect low weld metal ductilities. Similarly, the low total elongations across the weld do not indicate poor ductility of the weldment in comparison with the parent metal. Loading of a composite specimen, in which the weld metal has a yield strength considerably greater than that of the parent metal, will force plastic straining (deformation) to take place preferentially in the parent metal. In many cases failure in the parent metal occurs while the weld metal still is below its elastic limit; therefore, when the load is released by the failure, no measurable plastic strain is noted for the weld metal. The low total elongations similarly reflect the effective rigidity of the weld metal, so that the measured total strain actually is that of parent metal of a considerably shorter length than the 2-in. gage length for which the percentage elongation had been calculated.

It may be noted that the tensile test results for as-welded butt welds made using a −60° F prefreeze and interpass temperature were comparable to those using ambient preheat and interpass temperature (room temperature to 200° F).

Bend Tests of Flat Position Butt Welds. The side-bend test results, in Table 3, indicate a definite superiority of the 0.5% Cr – 0.5% Mo and 1% Cr – 0.5% Mo low-hydrogen electrode weld metals, as-welded, over the 0.5% Cr – 0.5% Mo cellulose-titania electrode weld metal, regardless of whether the latter is in the as-welded or in the preheated and postheat treated condition. The higher chromium low-hydrogen electrode weld metal had some tendency to fail in this test by propagation of a crack from an unfused root condition (no backing straps were used), but such failures did not amount to complete fractures as in the cellulose-titania electrode weld metals (see Table 3). The severity of the side bend test accentuates the crack initiating tendencies of incomplete root penetration; some of the root tears noted, which were longer than the 1/8-in. maximum length allowable, certainly would have been minimized or eliminated had the weldments been made by using a backing strap.

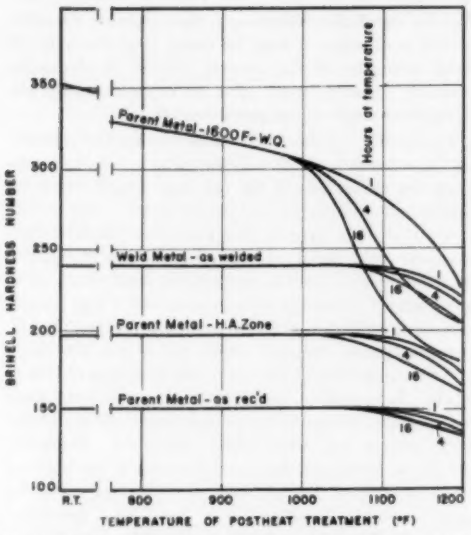

Fig. 1 Effects of postheat treatment on hardness of 0.5% chromium – 0.5% molybdenum weld and parent metal (Code B electrode used)

The free-bend test results, also shown in Table 3, indicated relatively low ductility for all of the welds, including the postheat-treated cellulose-titania electrode weld. The weld metal elongations are considerably below the ASME Boiler Code requirements of 25% minimum for nonstress-relieved welds. The low values of elongation are to be expected, in view of similar results from the tensile tests, and reflect the inherently higher strength of the weld metals, which forces most of the elongation in the free-bend test specimen to take place in the parent metal.

Side-bend test results for low-hydrogen electrode welds made using a −60° F prefreeze and interpass temperature were similar to those using ambient preheat and interpass temperature (room temperature to 200° F).

Hardness Surveys of Flat Position Butt Welds. The hardness surveys of the welds made with the various electrodes indicate comparable heat-affected zone hardnesses in the as-welded condition, as shown in Table 3. Stress-relieving for as long as 8 hr at 1050° F appeared to have little, if any, effect in reducing the heat-affected zone hardnesses. Postweld heat treatments of 1250° F for 1 hr or 1200° F for 16 hr lowered the heat-affected zone hardness, but in no case was the final hardness as low as that of the as-received pipe (see Table 4). The effect of postweld heat treatments on the hardnesses of the various weld metals was similar to that noted for the heat-affected zones of the welds. Figure 1 illustrates the response of the Code B weld metal and the parent metal to postheat treatments at various temperatures for holding times of 1 to 16 hr.

Table 4—Hardness of Heat Treated 0.5% Cr-0.5% Mo Steel Pipe

Condition	*Avg Brinell hardness*[a]
As-received	142
As-received; 1050° F-8 hr draw	144
As-received; 1200° F-16 hr draw	131
As-received; 1250° F-1 hr draw	130
1600° F-2 hr-water quenched	358
1600° F-2 hr-water quenched; 1050° F-8 hr temper	277
1600° F-2 hr.-water quenched; 1200° F-16 hr temper	180

[a] Converted from Rockwell hardness data.

The hardness of the weld heat-affected zone, for all of the electrodes used, generally was lower than that of the parent metal as quenched, or as quenched and tempered (postheat treated) at comparable temperature for similar times (see Table 4). The 1200° F-16 hr and 1250° F-1 hr treatments were effective in reducing hardness of the as-received parent metal.

The hardnesses of as-welded low-hydrogen electrode weld metals and heat-affected zones were comparable regardless of whether ambient preheat and interpass temperatures or −60° F prefreeze and interpass temperatures were employed. There appears to be no clear-cut correlation between the hardness of a particular weldment and its mechanical properties, especially in relation to ductility.

Impact Properties of Flat Position Butt Welds. Room temperature Charpy impact tests of the 0.5% Cr – 0.5% Mo steel pipe and welds indicated that, for comparable treatments, the various weld metals absorbed less energy to fracture than did the parent metal (see Table 5). However, the impact properties of the heat-affected (fusion) zones, as-welded, were comparable to those of the as-received pipe material. The postweld heat treatments, in general, appeared to result in only a slight increase in the energy absorbed by the various weld metals, although the parent metal exhibited a considerable increase in energy absorption. The use of low initial and interpass temperatures (−60° F) had little effect on the room temperature impact properties of the weld metals deposited from 0.5% Cr – 0.5% Mo and 1% Cr – 0.5% Mo electrodes.

The transition temperatures determined for the various weld metals and pipe material, using the two criteria of 50% of the maximum energy absorbed and of 15 ft-lb energy absorbed, are listed in Table 5. The results indicate that all of the as-welded low-hydrogen weld metals had a transition temperature lower than that of the parent metal. Postweld heat treatment of 8 hr at 1050° F raised the transition temperature of the weld metals (for one electrode brand apparently to a temperature higher than that of the as-received pipe material), whereas a postweld heat treatment of 16 hr at 1200° F seemed to have no significant effect on the transition temperature of the weld metal, other than to reduce the scatter of the data (temperature range of the transition zone). Typical results for the

Table 5—Impact Properties of Flat Position Butt Welds in 0.5% Cr – 0.5% Mo Steel Pipe

Standard Charpy-keyhole notch specimens

Electrode brand	AWS type	Condition or treatment	Energy absorbed, ft-lb at +80° F: Parent metal	Energy absorbed, ft-lb at +80° F: Fusion zone	Energy absorbed, ft-lb at +80° F: Weld metal	Trans. temp., ° F, 50% energy level: Parent metal	Trans. temp., ° F, 50% energy level: Weld metal	Trans. temp., ° F, 15 ft-lb energy: Parent metal	Trans. temp., ° F, 15 ft-lb energy: Weld metal
Code A	E8013	As-welded[a]	58–65	58–62	19–30	+1 ± 16	....	−38 ± 18	....
		550° F preheat; 1250° F-1 hr stress relief	84–94	89–95	29–35	....	....	....	....
Code B	E7015	−60° F prefreeze; as-welded	...	50–56	35–36	....	....	....	....
		As-welded[a]	...	44–53	31–36	....	−86 ± 17	....	−90 ± 14
		No preheat; 1050 F-8 hr stress relief	...	...	36–38	....	−37 ± 19	....	−48 ± 18
		No preheat; 1200° F–16 hr stress relief	...	...	45–46	....	−88 ± 5	....	−93 ± 4
Code C	E8015	−60° F prefreeze; as-welded	...	52–60	37–40	....	....	....	....
		As-welded[a]	...	46–58	31–38	....	....	....	....
Code D	E8016	−60° F prefreeze; as-welded	...	41–60	32–34	....	....	....	....
		As-welded[a]	...	35–49	28–38	....	−48 ± 18	....	−61 ± 19
		No preheat; 1050° F-8 hr stress relief	...	...	34–35	....	+36 ± 27	....	+18 ± 26

[a] Preheat and interpass temperatures under 200° F. No postheat.

Code B electrode welds and the parent metal are illustrated in Fig. 2.

Properties of Positioned Butt Welds. The results of tests of butt welds in 0.5% Cr – 0.5% Mo steel pipe which were welded in the horizontal fixed position (comparable to vertical and overhead welding) indicated that mechanical properties of the weldments could be obtained which were equivalent to those of the flat position butt welds. The low-hydrogen electrodes exhibited good usability characteristics for all-position welding; in fact, somewhat better root penetration was secured in the vertical and overhead positions than in the flat position. This latter result, however, may be attributable more to welding operator technique in manipulation than to any inherent electrode characteristic. In any event, the better root penetration produced somewhat better side-bend test results, in that less tearing from unfused roots was observed in the vertical and overhead butt welds than in the flat position welds.

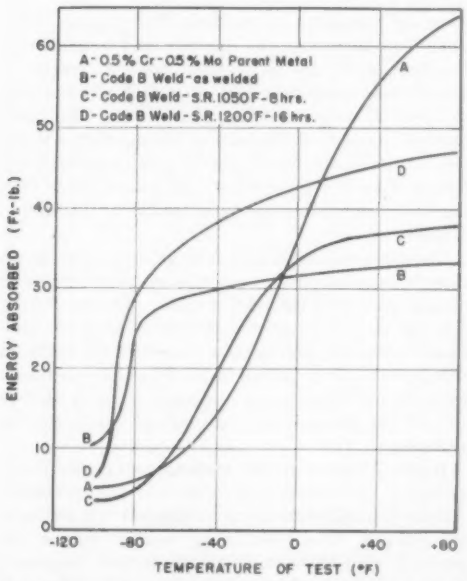

Fig. 2 Effect of test temperature on Charpy keyhole notch impact properties of 0.5% chromium – 0.5% molybdenum weld and parent metal

1.25% Cr – 0.5% Mo Steel

The limited results obtained on the mechanical properties of welded 1.25% Cr – 0.5% Mo steel pipe are shown in Table 6. In general, the tensile, ductility and side-bend test properties of the as-welded weldments are satisfactory. The 450° F preheat, 1350° F-1/2 hr postweld heat treatment resulted in a slight decrease in the ultimate strength and in the heat-affected zone and weld metal hardnesses, and an increase in the weld metal ductility (as determined in a tensile test). The side-bend test results for both as-welded and thermally treated weldments are comparable.

General comments relative to the low values of elongation measured in the weld metal, as discussed above for the 0.5% Cr – 0.5% Mo steel pipe welds, also apply to the results obtained for the 1.25% Cr – 0.5% Mo steel pipe welds.

DISCUSSION

The established procedures for fabricating plain carbon steels by welding, using standard cellulosic electrodes, frequently involve the use of both preheating before welding and postheating (stress relief) after welding. The applicable Codes for unfired pressure vessels and piping, in particular the ASME and the API-ASME Codes, emphasize the stress-relieving requirement.[5]

Table 6—Mechanical Properties of Flat Position Butt Welds in 1.25% Cr – 0.5% Mo Steel Pipe

Electrode brand	AWS type	Treatment of weldment	Tensile tests[a] Ultimate strength, psi[b]	Elongation, % Weld	Elongation, % Total in 2 in.	Hardness tests[c] H-A Avg	Hardness tests[c] Zone Max	Hardness tests[c] Weld Avg	Hardness tests[c] Weld Max	Side-bend tests Passed	Side-bend tests Failed,[d]	Remarks
Code C	E8015	As-welded[e]	78,900	1.6	25.0	228	240	187	228	4	0	.....
		450° F preheat; 1350° F-1½ hr stress relief	75,900	9.5	28.0	176	219	165	185	4	0	.....
Code D	E8016	As-welded[e]	77,600	1.7	23.0	222	246	200	225	3	1	Root defects
		450° F preheat; 1350° F-1½ hr stress relief	75,500	5.5	27.5	185	200	180	200	3	3	Face tear
Code E	E9015	As-welded[e]	79,800	0.8	22.0	231	246	231	275	4	0	.....
		450° F preheat; 1350° F-1½ hr stress relief	75,500	3.3	25.5	174	195	187	202	3	1	Root tear
Code F	E9015	As-welded[e]	79,300	0.8	22.0	237	252	231	264	1	2	Unfused root
		450° F preheat; 1350° F-1½ hr stress relief	76,500	6.5	28.0	182	200	176	195	4	0	Slight root tear

[a] Reduced section tensile specimens—weld reinforcement removed. Results average of two specimens. All failures occurred in the parent metal.

[b] Parent metal—Ultimate strength, 73,500 psi; elongation 35% in 2 in.

[c] Brinell hardness numbers converted from Rockwell hardness data. Parent metal, as-received—160 Brinell average.

[d] Specimens showing a crack or other defect exceeding ⅛ in. in length were considered to have failed.

[e] Preheat and interpass temperature under 200° F. No postheat.

Preheat Treatments

The purpose of preheat treatments is to make more gradual the thermal gradient between the weld metal and the otherwise relatively cool base metal. The physical effects of preheating are to minimize warping or distortion and to minimize or eliminate cracking, particularly in root passes, in welds made under moderate to high conditions of restraint. The ultimate metallurgical effects of preheating are to produce softer structural components in the heat-affected zone of the base metal; these are a consequence of the less drastic quenching which results when the temperature gradient during welding is reduced by increasing the temperature of the parent plate. Recommended preheat temperatures range from about 100° F for plain low-carbon steels to 600–800° F for high-carbon or high-alloy hardenable grades of steel.

Necessity for Preheat in Welding 0.5% Cr – 0.5% Mo Steel Pipe

The extent to which thermal treatment actually is required in welding 0.5% Cr – 0.5% Mo steel pipe can be judged by an over-all consideration of the results of the study made. The data indicated adequate ductility and strength for 0.5 to 1% Cr – 0.5% Mo low-hydrogen welds in 0.5% Cr – 0.5% Mo steel pipe regardless of whether the metal welded was at −60° F or at 200° F. Thus, preheat for the purpose of obtaining softer or tougher heat-affected zones does not appear to be warranted. However, the test welds made do not represent conditions of high restraint, such as might exist when making a tie-in weld in the field between long runs of pipe; under these conditions it is possible that cracking of root passes may occur in the absence of some preheat. From a practical viewpoint, therefore, preheating does no harm and may be beneficial under some conditions.

Postheat Treatments

Postheat treatments are employed in an attempt to reduce the hardness in the weld heat-affected zone and to relieve residual stresses set up in the weld and heat-affected zones as a result of the contraction of the weld metal during cooling from high temperatures. The physical effects desired in postheating are a lowering of the residual stresses by relaxation, and, when dimensional stability is required, an elimination of distortions during subsequent machining operations. The metallurgical effects of postheating are to temper any hardened structures in the heat-affected zone of the weld, thus increasing the ductility and toughness of this portion of the weldment. Postheat treatment temperatures range from 900 to 1500° F with the 1150 to 1350° F range most frequently used. The times used are normally of the order of 1 hr per inch of thickness at the maximum temperature or proportionately longer at lower temperatures. In general, slow cooling following postheating is advisable to insure uniformity.

Thermal treatments, especially at elevated temperatures, represent a considerable expense which frequently exceeds the cost of the welding alone. The use of these treatments in field-erected structures imposes additional difficulties, and in many instances the optimum temperatures cannot be reached. When lower temperatures are used there is a considerable question whether or not the purposes of the postheat treatment are achieved.

Rigid adherence to the requirements of the Codes in regard to thermal treatments will not necessarily insure optimum properties in a weldment. It is known, for example, that postheating usually reduces the strength of weld metal somewhat, and frequently reduces the strength of the parent metal in the weld zone also. In addition, some weld deposits, as reported by Smith,[7] particularly those from low-alloy, high-

strength, low-hydrogen type electrodes, and some parent metals may be temper embrittled to some extent after treatment in the 1050 to 1150° F temperature range normally used for postheating. Furthermore, it is obvious that weld metal or underbead cracks, resulting from inadequate preheating or from incorrect electrode usage, cannot be alleviated by a postheating treatment after they have occurred.

Effectiveness of Postheat Treatments for Relieving Stresses

A prevalent concept of the role of postheating in welded fabrication is to eliminate residual stresses in the structure. Basically, residual stresses can be relieved only by plastic yielding, and the lowest stress level which can result is that corresponding to values falling somewhere between the proportional limit and the so-called yield strength (practically, the stress to produce 0.2% elongation) of the metal at the postheating temperature being used. These properties, determined for several steels at elevated temperatures from various short-time, high-temperature tensile tests [8,9] are illustrated in Fig. 3. Thus, residual stresses in a plain carbon steel weldment possibly cannot be lowered below some value of the order of 6000 psi, if the weldment is postheated at 1200° F for any reasonable time. However, at this same temperature, the corresponding residual stress value for a carbon – 0.5% Mo steel will be of the order of 8500 psi, and for a 2.25% Cr – 1.0% Mo steel it will be of the order of 17,000 psi. It is interesting to note that, contrary to usual belief, residual stresses in 0.5% Cr – 0.5% Mo weldments should be higher than those in 1.25% Cr – 0.5% Mo or 2.25% Cr – 1.0% Mo weldments. It does not necessarily follow, however, that these nominal stress levels always will be reached whenever postheating is employed, nor must it be assumed that all welds will contain mean residual stresses of greater magnitude than these stress levels.

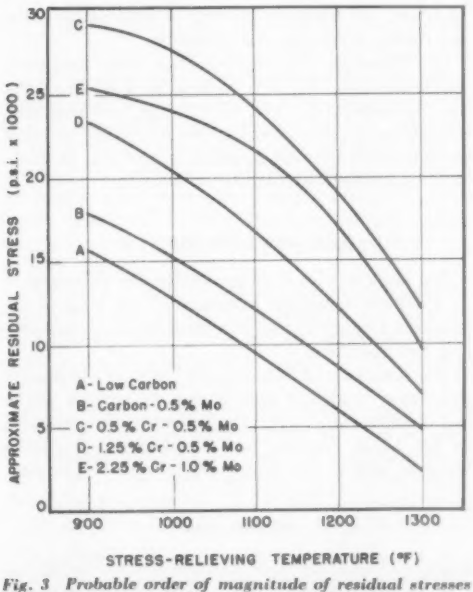

Fig. 3 Probable order of magnitude of residual stresses in various carbon and chromium-molybdenum steels after postheat treatment for any reasonable time of heat treatment

Practically, the most significant effect of postheating probably is to heat the vessel to an elevated temperature while it is unloaded except for its own restraints and, thus, to permit redistribution of localized peak stresses which are introduced as a result of local restraints, section thickness variations or the welding technique used. In this connection it may be noted that, unless adequate precautions are observed to maintain temperature uniformity during the cooling of a weldment after postheating, rather high residual stresses may be reintroduced, thus negating, in effect, any benefits which may have been derived from heating to and holding at the elevated temperature.

Low-Temperature Stress-Relieving Treatments

The difficulties inherent in securing adequate temperatures and temperature uniformity in postheating field-erected structures have led some authorities to advocate lower temperatures for stress-relieving purposes. It is questionable whether these treatments are in any way effective, particularly in comparison with the natural relief of stresses resulting from extended service of units operating at elevated temperatures. In some instances rather effective stress relief is afforded merely by mechanical means alone; peening of weld metal is resorted to for this purpose. Hydrostatic testing frequently can relieve stresses by the mechanical deformations which usually accompany the load application. The so-called low-temperature stress-relief treatment, in which 3- to 4-in. wide bands of the base metal on both sides of a weld are heated to only 350–400° F, is effective by permitting a redistribution of stresses from localized high-peak stressed areas. The over-all average residual stress level probably remains unchanged or is lowered only slightly. deGarmo[10] has evaluated the low-temperature stress-relieving treatment in comparison with results obtained with preheat and postheat treatments.

Necessity for Postheat in Welding 0.5% Cr – 0.5% Mo Steel Pipe

Postheating of 0.5 to 1% Cr – 0.5% Mo low-hydrogen welds in 0.5% Cr – 0.5% Mo steel pipe produced no significant changes in the heat-affected zone metal structures. Treatment at about 1200° F reduced the hardness of the weld and heat-affected zone, but, in view of the adequate ductility and toughness of this material even in the as-welded condition, reduction of hardness alone does not justify the cost of the post-

heat treatment. Furthermore, the use of postheating temperatures in the 1050–1150° F range resulted in a reduction of the impact toughness of the 0.5 to 1% Cr – 0.5% Mo weld metal. The use of temperatures below 1050° F is relatively ineffective in reducing residual stresses, because of the high elevated temperature yield strengths of these low-alloy chromium-molybdenum steels. To be completely effective, therefore, postheat, if used, must be conducted at temperatures of 1250° F or over; these temperatures are difficult to obtain and maintain under field conditions, especially for large vessels. Shop weldments, except for certain large vessels, seldom represent high restraint welding, and these normally will not exhibit high levels of residual stresses. The expense involved in postheat treatment of 0.5 to 1% Cr – 0.5% Mo welds in 0.5% Cr – 0.5% Mo steel pipe, in particular, therefore appears to be unwarranted. Nevertheless, postheat treatments frequently are used because they can be given relatively inexpensively in the shop when large furnaces, etc., are available. In reference to postheat treatment, cognizance also must be given to the specific requirements of the several applicable Codes, if Code-approved vessels or piping are desired. In these cases, postheat at a minimum of 1250° F for at least 1 hr per inch of thickness or fraction thereof should be used for 0.5 to 1% Cr – 0.5% Mo welds in 0.5% Cr – 0.5% Mo steel. At a temperature of 1200° F a minimum time of 2 hr, and at a temperature of 1150° F, a minimum time of 8 hr is indicated.

SUMMARY

On the basis of the results obtained in this investigation of the arc welding of 0.5% Cr – 0.5% Mo steel pipe it is concluded that:

1. Welds of satisfactory quality and properties can be made in all positions using either 0.5% Cr – 0.5% Mo or 1% Cr – 0.5% Mo low-hydrogen electrodes without preheating or postweld heat treating.

2. The properties of welds made with conventional 0.5% Cr – 0.5% Mo cellulose-titania electrodes, either with or without preheating and postweld heat treating, were inferior to those of the low-hydrogen electrode welds, as-welded.

3. None of the welds made in this investigation could pass the free-bend test because the weld metal has considerably higher strength than the parent plate. However, other tests indicated adequate ductility, for the low-hydrogen electrode welds in particular.

4. The impact properties of low-hydrogen welds are adequate, both at room temperature and at somewhat lower temperatures. The transition temperatures for the low-hydrogen weld metals, as-welded, are lower than that of the parent metal, based on either of the criteria of 50% of maximum absorbed energy or of a 15 ft-lb level of absorbed energy.

5. Prefreeze and interpass temperatures of −60° F have little, if any, effect on low-hydrogen welds in 0.5% Cr – 0.5% Mo steel pipe, as judged by the fact that subsequently they exhibit adequate room temperature physical properties.

6. A postweld heat treatment of up to 8 hr at 1050° F produces no improvement in physical properties and no significant metallurgical changes in low-hydrogen electrode welds in 0.5% Mo steel pipe. However, some impairment of low-temperature impact properties is produced by this treatment, since the transition temperature is increased appreciably.

7. Postweld heat treatment of 16 hr at 1200° F or, possibly, about 1–2 hr at 1250° F, produces relatively little improvement in the properties, some reduction in weld metal and heat-affected zone hardnesses, no appreciable metallurgical changes and relatively little change in impact properties, both at room and at somewhat lower temperatures (transition temperature), of low-hydrogen welds in 0.5% Cr – 0.5% Mo steel pipe.

8. Weldability and usability characteristics of the 0.5% Cr – 0.5% Mo and 1% Cr – 0.5% Mo low-hydrogen electrodes were found to be very good. Satisfactory welds were made in 0.5% Cr – 0.5% Mo steel pipe, in the as-welded condition, for all positions of welding, and at pipe temperatures as low as −60° F.

9. In order to avoid weld metal hardnesses, in the as-welded condition, which may be excessive, it appears desirable to limit the maximum chromium content of the electrodes to 1%. Likewise, low-hydrogen electrodes which deposit 0.5% Cr – 0.5% Mo weld metal are preferable to the 1% Cr – 0.5% Mo varieties.

10. The low-hydrogen electrode is somewhat more difficult to use than the conventional cellulosic-type electrode, but adequate training of welding operators can readily eliminate this difficulty.

11. Although this investigation was concerned specifically with the arc welding of 0.5% Cr – 0.5% Mo steel pipe, 5-in. O.D. by 0.750-in. wall thickness, the results are considered to be applicable to other size pipes or tubes, and to plates up to $^3/_4$ in. in thickness, whose chemical composition is similar.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of C. F. Braun and other personnel of the Engineering Research Department for the preparation of the welds and test specimens.

The permission of Standard Oil Co. (Ind.) to publish this paper is greatly appreciated, as are the advice and encouragement given throughout the investigation by Dr. C. H. Samans, Associate Director, Materials Division, and G. W. Watts, Director of Engineering.

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Prevention of Marine Corrosion by Metallizing Systems

A method has been developed for spraying zinc or aluminum to protect marine equipment over a period of the life of the ship

by Howard Vanderpool

INTRODUCTION

STEEL is one of the most easily corroded metals known to man. Nevertheless, we build ships of steel. It is inexpensive, easily welded and strong structurally, and as long as we can economically apply innumerable coats of paint, we can afford to use this very elusive metal. But times change and the cost of labor soars inevitably. The application of a succession of paint coats, with the almost invariable need for scraping and wire brushing, causes the use of steel to become less economical. Further, assuming that a dollar spent today is worth a dollar, then, as sure as death and taxes, it will be worth less next year, necessitating the expenditure of more than a dollar for the same work. Put another way, the more dollars we put in real property today, the more value we will own one year from now.

The point is this, in welded ship construction we must eliminate, as much as possible, future labor costs because future labor will be purchased with a woefully inflated dollar, in addition to the fact that hourly rates are on the rise.

These things are recognized by management. That is why ship owners are focusing their attention on ways to eliminate weak links. They are searching for a means to fortify that factor of construction which shows the first sign of failure, that aspect of maintenance which will be first to cause an undue expenditure of dollars.

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Scheduled for presentation at the Thirty-Third Annual Meeting, AWS, Philadelphia, Pa., week of Oct. 20, 1952. Closing date for discussion Nov. 15, 1952.

Corrosion of steel is the culprit. Not only in marine work is this true but in the railroad industry and in public works, both big users of steel. Metallizing is one of the ways and means of eliminating this culprit. Metallizing has suddenly taken on a new aura of importance, because it is a *long-term* method of preventing corrosion.

Because of the confusion involved in the use of the terms "metal spraying," "spray welding" and "zinc or aluminum spraying," the original work *metallizing* has come to be used most universally. The term "metallizing" refers to the deposition of molten metal to a prepared surface with a metallizing gun. The term "metallizing *systems*" refers to metallizing plus a specific organic topcoat.

These processes may be used for two general groups of application: The first is Machine Element Work, as in returning a worn tail shaft to original dimensions, or hard surfacing a pump shaft in the packing gland, or applying coatings of stainless steel, Monel bronze or babbitt for their particular desirable characteristics. Recommended practices for these applications have been written by the Metallizing Committee of the AMERICAN WELDING SOCIETY and are available. The reference is Metallizing, Recommended Practices—Part 1-A.

The second group of applications is corrosion-prevention work on iron and steel. This is our subject as it applies to welded steel construction in the marine field.

CORROSION

Some understanding of the chemistry of corrosion is vital to the full utilization of any means of prevention. It is generally considered by corrosion engineers

that the reaction is electrochemical in nature; this is to say, that a current of electricity is present in all cases and this flow is the cause of the conversion of the attacked metal (steel) to the products of corrosion (rust).

It has been shown, that at least four conditions are necessary for corrosion to exist.

1. A relatively positive area called an anode.
2. A relatively negative area called a cathode.
3. A current-carrying liquid, the electrolyte.
4. An electrical conductor between anode and cathode.

A table of common metals exists which shows, in sequence, the relative electrolytic potential of these metals in sea water. If two of these metals are connected with a wire to a galvanometer and are immersed in sea water, a current will be indicated by the meter. The current will flow in a direction relative to the position of the metals. This action is similar to the chemical production of current in a cell of a common battery. If an electrical circuit is maintained across the post of a battery, current will flow until the positive plate has dissipated itself. This action preferentially attacks the anode. The higher the rate of current flow, the higher the rate of corrosion of dissipation of the anode.

Differences in the composition of one metal will act as two plates or electrodes. Differences in concentration or aeration of the electrolyte will produce areas of different potentials.

To evaluate the metallizing process, we compare it to methods in general use, so we will briefly discuss these, as they relate to electrochemical attack.

PAINT

The use of paint attempts to reduce the corrosion-producing current by providing a barrier to the electrolyte. Logically if no electrolyte comes in contact with the metal, no current will flow. If a film of inactive insulating material can be maintained in intimate contact with the steel, corrosion is effectively controlled. Unfortunately this is a difficult requirement. In spite of the development of modern organic materials important limitations still exist. Paints subjected to mechanical abuse will rupture, exposing the base metal. Water absorption, cracking and peeling also defeat the purpose by allowing the environment to contact the steel. When this happens, corrosion proceeds at the break or laterally beneath the surface and pitting results.

New synthetic substances (plastics) have been developed through organic chemistry, which possess a high degree of chemical resistance to corrosive environments and a low water absorption rate. Although they are generally harder than ordinary paints, they still are less resistant to abrasion than a metal. And most disappointing is their seeming lack of bond strength on steel.

GALVANIZING

In the marine field the use of galvanizing with zinc is an accepted method of protecting steel against the ravages of sea water and sea atmospheres. But this, too, has its limitations, which are size of works, difficulty or impossibility of doing "hot-dip" galvanizing at or near the site of erection and the maximum thickness of coating. The value of hot-dip galvanizing lies in its ability to provide a relatively positive film, an anode, thus reversing the potential so that the steel is a cathode. As a result of the anode's being sacrificial in nature, the protection afforded by a zinc coating is a function of its thickness or weight of coating. The writer has never observed a hot-dipped coating in excess of three mills.

STAINLESS AND CLAD METALS

Stainless steel, nickel or Monel clad steel as well as solid copper nickel alloys would offer a happy solution to many problems except for the cost involved. The writer very strongly recommends the use of these metals, clad or solid, in all cases where the cost can be justified. Certainly these are invaluable at present as components of ship construction.

CATHODIC PROTECTION

This method of combating corrosion makes use of an electromotive force or voltage which is applied to the corrosion cell in a direction that will oppose and thus negate the corrosion current. This is not entirely new to marine men. The zinc plates under the stern of a ship are a form of cathodic protection.

The name cathodic protection is derived from the fact that the positive potential makes the protected metal cathodic, thus it will not corrode. This means of rust prevention is only used in cases of immersion.

METALLIZING

Metallizing for corrosion work requires the use of a machine which, with the aid of oxygen, acetylene and compressed air, converts metal in the form of wire to small molten particles of that metal and propels them with high velocity onto a surface. The surface must be cleaned and roughened by blasting with an abrasive. Upon meeting the base metal or a previously sprayed surface, the molten particles become solid. Due to the minute size and low mass, the heat of each particle is carried away by contact with the base metal. Hence, although the temperature is at melting point, very little heat is produced in the coating.

Concerning the bond, it will suffice to say that zinc properly sprayed to a normal thickness will withstand repeated blows of a hammer and scraping with a knife.

It is absolutely necessary that care be exercised in keeping a surface to be sprayed free of contamination.

That is why specifications call for metallizing within a few hours after blasting.

There are means of controlling the thickness of coatings; one is to allow an appropriate weight of wire for any selected number of square feet for instance, if an area of 100 sq ft is to be sprayed to a thickness of 0.008 in., one could allow $^1/_3$ lb of zinc for each square foot or 35 lb for the area. To assure that even distribution of thickness is maintained, several gun passes are made at 90 deg. This is usually done over an area that can be comfortably reached by the individual operator. After a surface is up to thickness, it is checked with a magnetic-thickness gage. These gages can be read and are accurate to 0.0005 in. or $^1/_2$ mill.

Modern metallizing equipment is capable of spraying 61 lb of zinc per hour. This means a heavy coat of zinc can be applied over 123 sq ft in 1 hr. A light coat can be applied to 400 sq ft in 1 hr.

Costs of applying metallizing systems vary with the thickness of metal sprayed and the accessibility of the work. Heavy coatings consume more metal and extensive scaffolding is more expensive. Whenever possible metallizing is done prior to fabrication. Speed of deposition is important to low-cost metallizing, so modern metallizing guns are essential for economic reasons.

Oxygen to gas ratio must be maintained within reasonable limits for highest deposit efficiency and is controlled by oxygen and gas flowmeters.

METALLIZING SYSTEMS

Metallizing systems prevent rust by a combination of actions normally found singly in painting, hot-dip galvanizing and cathodic protection.

A typical metallizing system consists of a clean blasted steel surface, a coat of zinc or aluminum and one or more coats of an organic film, nothing more. The surface is virgin steel and is rough. The zinc or aluminum is of very high purity and the organic film if compatible with the zinc. No flux or pickling is involved in applying the zinc and no treatment is required, such as an acid wash, to prepare the zinc for the top coatings.

Zinc or aluminum is anodic to steel. Therein lies the major contribution of these metals as protective coatings. They hold a position above steel in the galvanic series. Coatings of bronze or stainless steel, for example, are both below steel and are cathodic to steel in sea water. Being cathodic, accelerates corrosion of the steel if a break in the coating occurs. On the other hand, zinc or aluminum if ruptured sets up a cell of a reverse potential. The steel is then cathodic and cannot corrode as long as the anodic metal is in the circuit. The zinc or aluminum in a cell is a sacrificial anode providing cathodic protection when needed. This action is similar in nature to the work of a zinc slab on the stern of a ship. The slab is a sacrificial anode attempting to protect the steel of the adjacent area. More accurately stated, it presents itself as a *more readily accessible* anode than the zinc in the brass, preventing dizincification or pitting of brass adjacent to the stern.

We stated that the zinc slab attempts to prevent corrosion of the steel. The reason it is not successful is because of the overwhelming area of steel or cathode in relation to the small zinc or anode. Now, if we spray the entire bottom with zinc, we eliminate the cathode by covering it, so that substantially the zinc will remain unaffected. If rupturing of the zinc film takes place, a small area of steel or cathode is exposed to a large area of zinc or anode, so the zinc proceeds to very capably prevent corrosion by its action as a sacrificial electrode.

In the early days of metallizing, experimental work included small test panels of zinc on bottoms of large ships. The zinc disappeared in one season. This was rather disappointing until we realized that the zinc, only a few mills thick and covering a small area, was acting as a sacrificial anode, attempting to prevent rust over all of the exposed hull below water line.

Now the question arises, "Why apply a paint or organic film over the anodic metal?" This is a good question and there is a good answer.

First of all, sprayed metal when first sprayed presents us with a surface about like No. 0 sand paper. The surface is actually porous, a fact that is in itself not a drawback as it is not intended as a barrier coat. Because it is rough and porous it, in effect, attracts initially liquid films. In other words, metallizing is an ideal base for paint.

Because of the above condition, a limitation of some plastic materials is removed, that of difficulty of obtaining a good bond. Many authorities on corrosion advocate the use of a very thin coat of zinc or aluminum as a base for paint. Thicker coatings of paints are possible over this rough surface. It is estimated that paint life can be extended from two to five times by use of sprayed metal as a base. Likewise, the life of zinc can be extended two to three times by use of paint.

Now we see that painting fits in with metallizing but "what exactly is the function of the paint or organic film?" First, a good plastic organic material of the vinyl or chlorinated rubber types is chemically resistant to many environments, it in itself resists moisture absorption, it is harder than oil paints and over sprayed metal it bonds well, resisting chipping. So we have an ideal barrier paint coat over an ideal anodic metal coat.

The marriage of plastics to metallizing is a cooperative proposition as all marriages should be. The metal coat has a disadvantage which is compensated for by the plastic coat. The porous surface of sprayed metal presents a large surface to the environment but the plastic material serves to seal this porosity. In fact, the barrier action of the paint insulates the zinc from the electrolyte except at a break when the zinc prevents

pitting and lateral corrosion which the paint alone could not readily handle. It is generally accepted that these combined actions provide a very much superior means of corrosion protection.

In the fabrication of welded steel ships removal of slag from the weld areas has long been a problem. Slag is cathodic to steel and therefore is a source of initial corrosion, many times resulting in fracturing at or adjacent to the weld. This is commonly referred to as preferential corrosion. Standard metallizing procedures eliminate the danger of fracturing from this source. Removal of slag by the use of chipping hammers is not necessary because the metallizing preparation accomplishes this. Further, the presence of the anodic metal keeps the weld area cathodic and noncorrosive.

The use of galvanizing sheet in construction of welded seine boats necessitated the use of metallizing to protect the areas around the welds due to removal of zinc by the welding operation. This procedure has been changed at one ship yard to the use of uncoated mild steel and instead of metallizing only the weld areas the entire hull is treated, inside and out.

The Panama Canal authorities conducted under-water tests of coatings on steel lock gates to determine the best system for protecting exposed equipment. This involved laboratory work and 8 yr of actual exposure tests. The following is a quotation from their summary as printed in *Corrosion*,* the official publication of the National Association of Corrosion Engineers.

The following are the major conclusions:

(*a*) "The systems which show outstanding performance are those which have been zinc metallized.

(*b*) "Zinc metallizing provides a sacrificial prime coat which acts as secondary protection if and when the organic top coats have deteriorated or become damaged."

Recent inspection of Dam Gates in the Susquehanna River produced some very interesting information. In 1937 (15 yr ago), as part of an independent test program, Gate 13 was zinc-coated. Except for the area adjacent to the bronze sealing strips, the entire gate was free from rust in the Spring of 1952. The zinc near the sealing strips not having an insulating coat of paint was exposed to the relatively active cathodic bronze. Acting as a sacrificial anode, it was rapidly dissipated back about 12 in. from the edges. This condition was hastily rectified by a reapplication of zinc plus two coats of a red lead, alkyd. Through the normal loss of zinc, accelerated by the absence of an organic top coat, the steel on the main area became exposed in between the heavy sections, yet no rust was in evidence on the exposed area after 15 yr.

The only conclusion regarding this phenomena so far advanced is that the remaining zinc, acting as a sacrificial anode, has prevented corrosion not only where it is still coating the steel but even where the steel has been exposed in large areas. In other words, in spite of the fact that a percentage of the area is not coated, corrosion has not taken place.

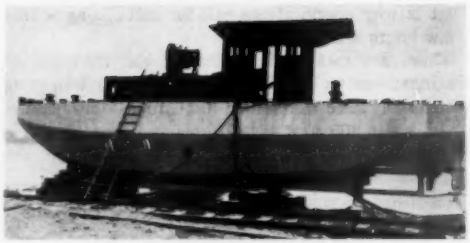


Fig. 1 Warner tug, welded steel construction, metallized on bottom. Not painted or drydocked for 15 yr. Courtesy, Metalweld, Inc., Philadelphia, Pa.

About 18 yr ago, the Warner Company of Philadelphia built a tug boat for use in their gravel pit near Trenton (Fig. 1). Due to lack of drydocking facilities in the land-locked lake, they required a means of protecting the hull for a very long period. Zinc was applied but no minimum thickness was specified. After 15 yr, an inspection revealed practically no corrosion although the zinc was gone. A logical explanation is that as large areas of steel became exposed at the thin section (recall that no organic coating was used), the sacrificial characteristics of the remaining zinc accelerated and probably had, only just prior to the inspection, completely disappeared.

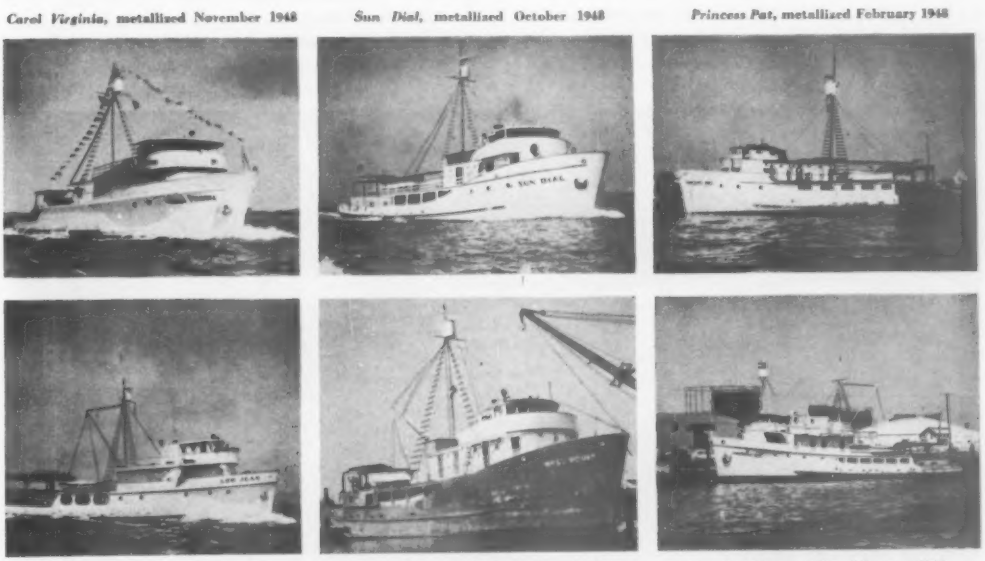
Irving Warner, Jr., of the same Warner Co., in 1948 was faced with loss of hull plates on the *Pennsbury* (Fig. 2) one of his Delaware River tugs, due to excessive pitting. His procedure of blasting and painting at frequent intervals was not the answer. With the writer's assistance, he worked out a system of metallizing. It was 0.010 in. of zinc with two coats of chlorinated rubber. After about six months the *Pennsbury* ran aground, buckling her bottom plates. Upon drydocking, the bottom treatment was found to be in excellent condition. The zinc was still intact on the buckled plates. This experience prompted the metallizing of the *Christina* a sister tug and subsequently two more vessels.

At this point, we should discuss the attachment of marine growth. Zinc with no organic coating is antifouling. It will resist marine attachment for 2 to 3 yr because, as sprayed, it is active. After this period, it passivates to an extent that a recommended antouling system should be applied. In the case of the Warner tugs in the Delaware, fouling was not a problem so a top treatment of plastic was included in the specification.

In April of 1950, Arthur Tickle of the Arthur Tickle Engineering Co., Brooklyn, N. Y., metallized the bottom of his yacht the *Steel Sylph*, using 0.010 in. of zinc with no subsequent organic treatment. After two seasons, there was no appreciable marine attachment. This hull was then treated with a recommended

* This report, dated March 1950, was based on investigations conducted by the Department of Operation and Maintenance, United States Panama Canal, Balboa Heights, Canal Zone. The excerpt printed was authorized for publication by Canal Zone authorities. A copy of the report was received by NACE Central Office on Aug. 28, 1950.

Fig. 2 Warner tug Pennsbury, welded steel. Metallized in 1948 to stop pitting evidenced in photo. Courtesy, Metallizing Engineering Co., Inc.



Carol Virginia, metallized November 1948

Sun Dial, metallized October 1948

Princess Pat, metallized February 1948

Lou Jean, metallized January 1947

West Point before being metallized in June 1948 with 0.012-in. thick coat of zinc. Coating still in excellent condition

American Boy, metallized January 1948

Fig. 3 West Coast Tuna Clippers metallized with zinc. Part of the fleet of welded steel Tuna Clippers operated by the Van Camp Sea Food Co. that have been metal sprayed for resistance to the corrosive action of salt water and air. Courtesy, Clark Metallizing, Inc., Newport Beach, Calif.

system of antifouling material. There has been no indication of rusting of the hull below the water line.

The following is a report of a steel-craft yacht the *Lady Liz*, which was treated with sprayed zinc on the hull. After two seasons on Long Island Sound and one season on the Hudson River, the hull is in excellent condition. No rust whatsoever was noted and the zinc on the bottom is perfectly intact. There were small scattered blisters here and there on the bottom, but these appeared during the first few weeks after metallizing and had not increased in size.

The original paint was in excellent condition after three seasons. The coating did not show any yellowing and was adhering perfectly. Gloss was about as good as when first applied.

Myles Read, the owner, plans to apply a vinyl system to the bottom, using a wash prime, two coats of anticorrosive vinyl and one or more vinyl-alkyd top coats. Since there is little or no fouling in this section of the Hudson, an antifouling paint is not needed. Mr. Read suggests that the bilge area also be metallized in future work on this type of vessel.

The welded steel Tuna Clipper, *Esperito Santo*, operating in Pacific waters, was metallized in 1946 by the Clark Metallizing Co., Newport Beach, Calif. This is a 500-ton vessel and is built of steel with light plating, generally $^1/_4$-in. and sometimes $^3/_{16}$-in. steel. Because of refrigeration used in preserving the fish until they reach port, much of the steel is inaccessible under the insulation. For this reason, it is imperative that a reliable method be used to prevent rust. Painted decks have been known to corrode through in four years. Interior of fish and bait tanks and welded joints in galvanized cooling coils are touched up at the same time.

Reduced stocking and maintenance costs have offset the initial expense in the first two years of operation. As a result of the work done on the *Esperito Santo*, some 88 vessels on the West Coast (Fig. 3), most of them Tuna Clippers, have been metallized in varying degrees.

A similar situation was experienced on the East Coast where newly constructed welded steel fishing vessels were found to have perforated plates in one or two seasons. One fleet owner now sprays all of his vessels either while in construction or after launching. Such areas as hulls, decks, coamings, fish holds net decks and railings have been given this zinc-organic coating treatment.

Although the work done in this category does not extend back more than 10 yr, in every case the metallizing has proved itself to be economically justifiable in the first few years of operation.

The yacht *Porte Bonheur* out of New Orleans was metallized in 1950 by the Avondale Marine Ways (0.010 in. of zinc below the water line with no subsequent treatment, 0.006 in. of zinc above the water line with one coat of primer, two coats of anticorrosive vinyl and two coats for color). Last inspection indicates entirely satisfactory results.

Another West Coast vessel which has attracted considerable attention because of the metallizing of its bottom is the *Chirikof* (Fig. 4).

The welded steel hull was prepared in the usual manner. The metallizing began immediately after blasting was completed, and all sections blasted were metallized before nightfall in order to prevent formation of rust due to condensation.

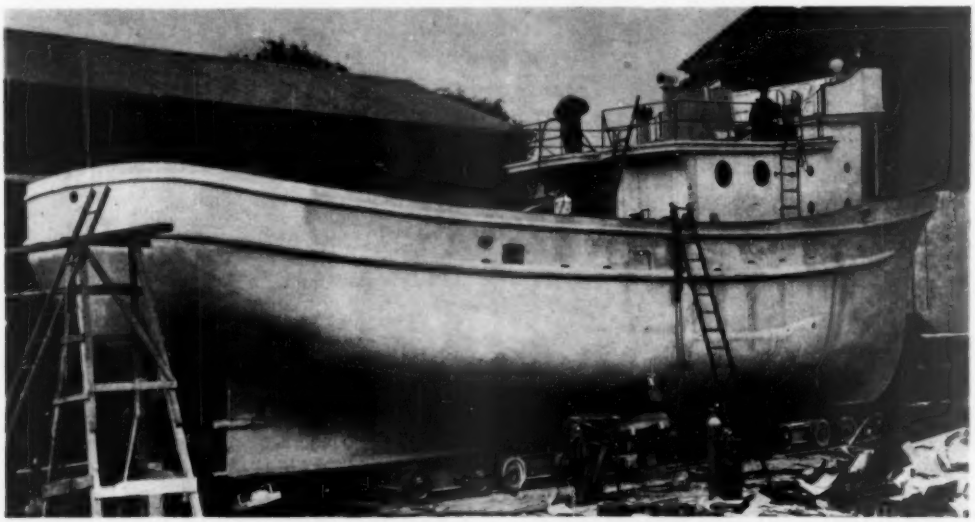


Fig 4 "Chirikof" welded steel hull metallized with zinc, 1946. Courtesy, Metallizing Engineerind Co., Inc.

Here is a report by N. C. Jannsen of the Jannsen Drilling & Mfg. Co., Seattle, Wash., which says, "The *Chirikof* has, of this date (1947), been in service for two years and there is no sign of any deterioration of the metallized surfaces even where the paint has been rubbed off. Just after the vessel was put into service, she had an accident going through the locks; this was caused by failure of the engine to reverse and resulted in a collision with one of the gates. The bow section was pushed back about six inches; yet even at the point of contact between the bow and the lock gate, there is no sign of coating failure.

"Another interesting point is that there is no sign of failure at the anchor roller where anchor chain and cable are in contact when letting out or taking in the anchor. Because of the success of the application on the hull, the owners are going to have the bulwarks and deck metallized. These areas were not included in the original job."

Another report, this one by Harry M. Guffey, Master and part owner of the *Chirikof*, states, "After some eighteen months in the water, meeting all the hazards of deep sea and coast fishing, the boat was drydocked. A particularly close inspection showed the zinc coating absolutely intact, even though the paint was gone entirely in many places. There was no corrosion and no appearance of electrolytic action on the stern. Extra zinc plates had been attached but even they did not show the usual attack from electrolysis.

"We feel that metallizing is the answer to the corrosion problem on steel marine equipment, particularly steel hulls. This job has paid for itself in the elimination of the seasonal chipping and scraping. Cleaning and painting is only a routine operation and the difference in labor and lost time will save the original extra cost many times during the life of the boat."

A more recent report received this Spring indicates that the original coating of zinc is still providing the protection that was found evidenced after two years of exposure. This story indicates 7 yr of hull bottom protection by sprayed zinc under the most severe service condition.

Probably the oldest metallizing job still in continuous service is the one done on about 14 large hulls in 1933. At this time, coal barges operating in the very corrosive waters of the Delaware River were given a zinc treatment by Metalweld, Inc., of Philadelphia. It is not known by the writer what the actual thickness was in thousandths of an inch; however, it is assumed that because the metallizing equipment used at that time did not spray metal at a very high rate of speed, a rather thin coating was used.

Previous to the zinc treatment, it was necessary to drydock these barges once a year at which time they were chipped, scraped and repainted. However, since metallizing has been employed, the procedure has been to pull the barges only every 2 yr and merely wash them down with a hose, after which they are ready for repainting. Thus labor costs for chipping and scraping have been eliminated entirely and drydock charges have been cut in half. After 17 yr of service, certain narrow sections at the water line were reblasted and resprayed. This necessity was accounted for by the severe trash and ice condition at this point and due to the fact that probably a rather thin coating of zinc was applied originally.

The University of Southern California has a Marine Laboratory called the *Velero IV*. This is a modern welded steel vessel of approximately 500 tons (Fig. 5). The appearance of this vessel is given considerable attention, and it was for this reason, among others, that a system of metallizing was used to prevent rust. After 4 yr of service in the warmer waters of the Pacific Ocean, this vessel is still in excellent shape as to appearance and lack of corrosion.

The following report was received from the Union Metallurgique, Ltd., 12 Rue Le Peletier, Paris, France.

Metallizing was used to a very large extent in the construction of the French superliners, the S.S. *Normandie* and the S.S. *Ile de France*. The following is a brief summary of the more important applications:

1. Entire system of ventilation and aeration.
2. Refrigerating plant.
3. Welded steel partitions and bulkheads.
4. All condensers and bronze valves.
5. Superstructure, including three large stacks and winter garden.
6. Hot- and cold-water pipes and piping for evacuation of dirty water as well as 400 castiron pedestals and table standards. Also, 2000 lighting fixtures.
7. Steel lifeboats and lifeboat equipment.

Fig. 5 University of Southern California welded steel Marine Laboratory used for oceanic research. Metallized with zinc. Courtesy, Clark Metallizing, Inc., Newport Beach, Calif.

Fig. 6 Tug boat ballast tank metallized with zinc prior to weldment of skin plates. Courtesy, Metallizing Engineering Co., Inc.

One of the world's largest tug boat operators uses metallizing to prevent corrosion. When possible, work is accomplished during construction. Figure 6 illustrates a system being applied to a ballast tank in the bow section before weldment of the skin plates.

Metallizing System Specifications

As a result of a need for standardization, 18 basic engineering specifications for metallizing systems* have been written by our company in conjunction with metallizing contractors in the United States and Great Britain. Metallizing specifications are being incorporated in the standard procedures being set up by the Metallizing Committee of the AMERICAN WELDING SOCIETY.

Considerable work is being done on protection of welded steel cargo tanks carrying fuel and chemicals. Reports of the success of this work will be available from our company's engineering department in the near future.

We must stress the importance of very careful supervision of the application of a metallizing system. Metallizing is a method of corrosion prevention which is generally done only once in the lifetime of a structure, so that obviously it pays to give attention to correct procedure.

Conclusions

We would like to state that the use of metallizing for the protection of welded steel marine equipment has gone far beyond the experimental stage. We do not know of any case where an approved system has reached the end of its service life. It has been proved many times that metallizing is justifiable on ship work because in almost every case history the cost of initial application has been justified in the first 2 to 4 yr of service.

It has been found in marine work that it is practical to spray ships new or old. There are, however, obvious advantages to doing the metallizing previous to or during the construction of the vessel.

There are difficulties involved in the application of sprayed metal as compared to the application of ordinary paint, but these are overwhelmingly compensated for by the permanent nature of the protection and the elimination of preferential corrosion of welds due to slag.

Thirty years of successful applications in the corrosion field indicate that metallizing is worthy of the most studied consideration by those men whose responsibility is the proper design and maintenance of welded steel marine equipment.

* These are specifications written for marine engineers, naval architects, ship owners and ship yards who anticipate the use of metallizing for corrosion prevention of iron and steel. Accepted procedures are outlined covering environments of atmospheres, water immersion, fresh and sea, as well as many chemical reagents. These are available free of charge from Metallizing Engineering Co., Inc., and metallizing contractors throughout the United States, Canada and Great Britain.

Fig. 1 Typical high-speed assembly line including several welding operations

Maintenance of Resistance Welders in High-Speed Assembly Lines

Assembly of small electrical parts at high rates of speed involve a determination of the best method of accomplishing the job including equipment, determination of tolerances, provision for changing electrodes, electrical considerations, timers and maintenance

by James F. Salatin and O. D. Etchison

REDUCTION of the downtime for repair of all industrial equipment is of very great importance. This is particularly true of resistance welders used in high-speed assembly lines, where parts are often assembled at speeds well above one thousand per hour. In such cases, many people may be dependent upon welding operations for a steady flow of work. At Delco-Remy Division of General Motors, assembly of small electrical parts at high rates of speed has reached a very advanced stage of development. The techniques described in this report are currently in operation in our Plant Six and have helped to make some remarkable production records. Figure 1 illustrates a typical high-speed assembly line including several welders. Since the introduction of these ideas about two years ago with approximately forty welders in operation, assembly line production has never been seriously curtailed due to a welder failure. Among these forty machines are two multiple head, special dial welders operating directly in the assembly line with no bank of parts on either side to lessen the effect of welder failure.

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To get the most from resistance welding on high-speed assembly lines several factors must be considered.

1. The process must be properly developed and engineered before attempting production.

2. Good quality equipment with simple controls and a minimum of mechanical gadgetry should be obtained.

3. Electrodes and dies must be designed for the best compromise between welding efficiency and long life.

4. A rapid system for replacement of parts and controls with subsequent repair, should be used.

5. Highly skilled personnel should be used to the best advantage.

Each of these factors may be readily apparent but are very important. Determining the best method of accomplishing a job and deciding the size and capacity of the equipment required is the first task to be accomplished. The importance of this step cannot be emphasized too strongly. It should be handled by engineers who are thoroughly trained in all aspects of welding and joining. Otherwise, the most economical and best joining methods cannot be assured. This stage is the base upon which the reputation of a welding process may depend.

It should be the task of these engineers to look into all methods of accomplishing a given job and evaluate each by experimentation. During the experimental work it is also possible to determine the size and capacity of equipment for production. Productive limits and tolerances must also be established. Limits and tolerances are the natural result of mass production. A product cannot be made if tolerances are not established. This is especially true of resistance welding. Line voltage fluctuation, contact resistance variation, small differences in the size and shape of production run parts, differences in the amount of plating as well as changes in electrode contours with wear are but a few of the many variables to be encountered. An engineer would be very foolish to recommend that a job be done by resistance welding unless he knew beforehand that good welds could be obtained in the laboratory under conditions which vary at least as much as the widest shop tolerances. If extra equipment such as synchronous timers and voltage or current regulators are necessary to bring variations into line, the process cost might be seriously affected and maintenance becomes complicated.

Once the practicability of the job has been determined, the task of selecting equipment may be started. Plant policies and the suggestions of reputable manufacturers should be used, along with the findings of the experimental engineer. Cooperation between the product engineers, production supervision and the equipment manufacturers will go a long way toward assuring success. Standard machines, that is machines which are produced in quantity, will offer less difficulty when it is necessary to obtain replacement parts. They will also be less expensive in first cost since engineering and tooling expenses are spread over a much larger number of machines. Figure 2 shows a special machine for welding a small tab to a bracket. Figure 3 shows one efficient method of doing the same job on a standard machine with a rotating fixture. Figure 4 shows a sliding fixture in which it is possible to make a weld in two locations on the same part without reloading. Such fixtures may make it possible to use standard machines for high production jobs. Even so, it is not always possible to find a standard machine to meet every production problem. Where special machines

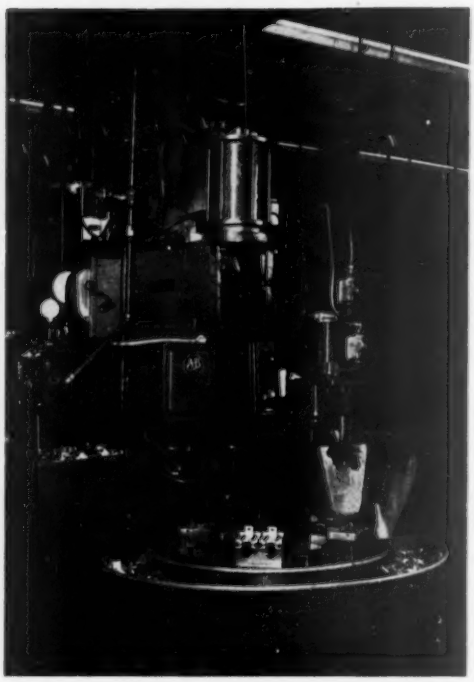

Fig. 2 Typical special dial welder for welding spring retainer to an angle bracket

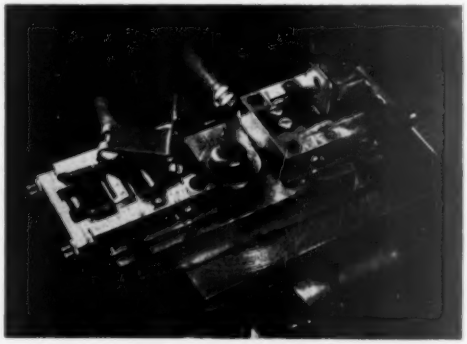

Fig. 3 Rotating fixture for use in a standard press-type welder for welding spring retainer to an angle bracket

are required the degree of specialization should be held to a minimum. If a department has the choice of one special machine using three operators, or four standard machines using four operators, it is well to study the situation carefully. The wages of the extra operator may be more than offset by:

1. Lower first cost of equipment.
2. Lower cost of dies and electrodes.
3. Greater departmental efficiency because production will not be entirely cut off while one machine is down for changing electrodes or repair.

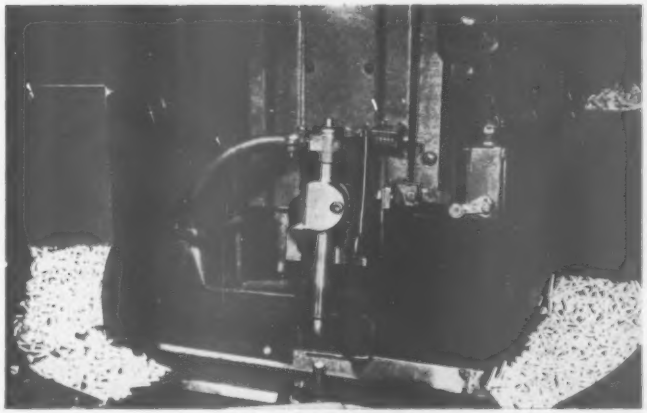

Fig. 5 One-way switch dog for operating air blast ejector as welder head returns to "up" position

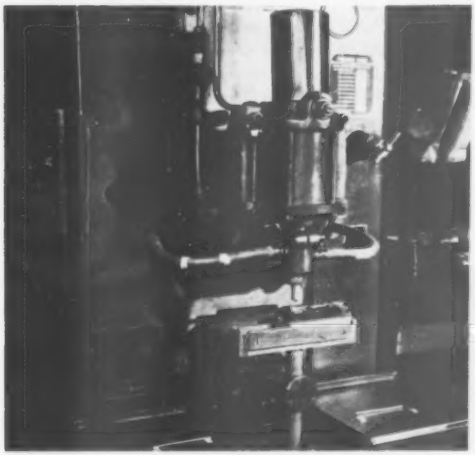

Fig. 4 Sliding fixture for welding at two different locations on the same part without removing it from the fixture

Fig. 6 Fixture for standard press-type welder where loading of a part forces a welded part to drop down the chute

4. Production troubles can be spotted in less time because tooling and controls are simple.

In essence, the flow of assembly line production will be curtailed less if standard machines with simple fixtures and controls are used. Many people may depend upon the welding operation for a steady flow of parts. With 120 operators behind a welder, each minute lost for repairs is 2 man-hours. It does not require many minutes at that rate to pay an extra operator's wages for several weeks.

The operating efficiency of standard machines can very often be brought close to that of special machines merely by the addition of an ejector device. If the operator can load a fixture, then immediately reach for the next set of parts while the welding operation is taking place, the production rate will be materially increased. Often the ejector device may be nothing more than an air blast controlled by a solenoid valve and a one-way, dog-type switch on the welder head. As the head travels up, the switch is operated, energizing the solenoid air valve to blow off the part. Traveling down, the head merely lifts the dog, the switch is not operated (Fig. 5). Other devices such as a simple plunger operated by an air cylinder or a solenoid may be used. It may even be possible to make the loading of a part push the welded part out of welding position and drop it down a chute as shown in Fig. 6. In most cases where small parts and assemblies are welded, it is not difficult to build simple ejector devices which aid materially in bringing the operating efficiency of standard machines close to that of a special machine. Such devices add little to the over-all cost of operation and maintenance.

Standard welding machines can also be used as com-

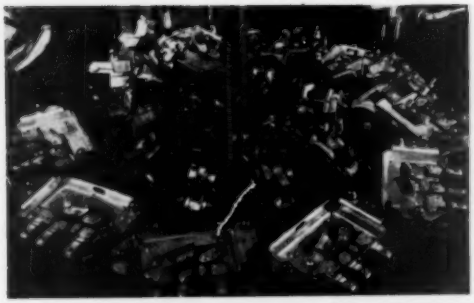

Fig. 7 Special dial-type dual welder for assembling resistors into regulator base

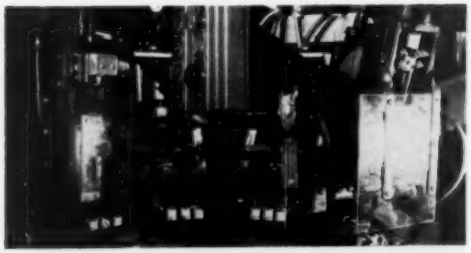

Fig. 8 Special dial-type triple welder for making regulator connections

ponents for more complicated special machines. Welding machine manufacturers have done this to some extent in their multiple spot welders and dial machines which have two or more welders around a dial table or fixture as illustrated in Figs. 7 and 8. Delco-Remy has gone a step further in developing what we call a straight line machine. Here several standard machines including welders, screwdrivers, presses and feeders may be combined around a chain conveyor which carries a number of work-holding fixtures under the various work stations (Fig. 9). In this type of assembly machine, a part is placed once and remains in the fixture until the assembly is completed. The chief value of this type of machine lies in material-handling savings. However, the point to be stressed here is that the welders incorporated into the machine are standard welders with standard controls. The only tie-in with the other parts of the machine is a cam switch for initiation and perhaps a switch to keep the welder from operating over empty stations.

Modern controls are necessary if consistent, good quality welding is to be accomplished. Ignition contactors and electronic timers have been proved to be accurate and relatively trouble free. Nevertheless the principle of using standardized equipment in the simplest manner possible will pay dividends in shorter periods of downtime. Every possible effort should be made to engineer the job so that simple nonsynchronous ignitron, timer installations will suffice. Only after

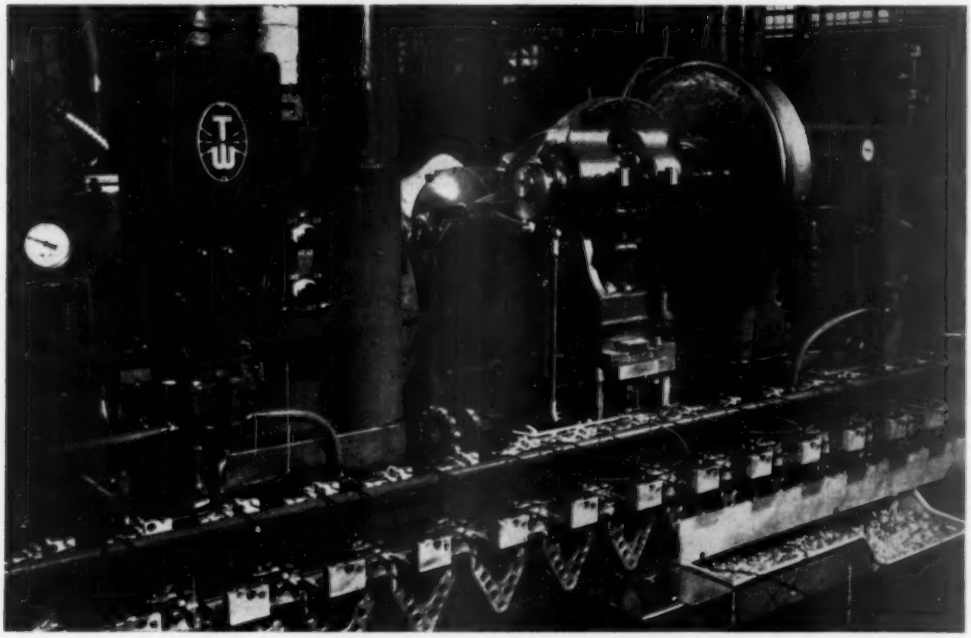

Fig. 9 Straight line machine incorporating a standard welder as one component

considerable investigation and planning, should special controls be placed on an assembly line. With increased complicity, added electronic tubes and more relays, maintenance time will increase.

The principle of simplicity and standardization should be applied to all phases of the welding machine. Air valves, cylinders and electrodes as well as mechanical parts should all be selected with the maintenance problem in view, particularly so when the welder is to operate as a part of an assembly line. Spare parts such as leathers, seals and gaskets should be kept on hand in quantity. They are not expensive; therefore, makeshift substitution for original parts, which adds to the repetitive maintenance, should not be necessary.

It is probable that on the average resistance welder application more production time will be lost in changing and repairing electrodes than in any other maintenance procedure. It is, therefore, essential that electrodes be designed using all of the latest information as to materials and their application. They must also be designed for rapid changing, an example of which is shown in Fig. 10. Most electrode changes should be scheduled during lunch periods and between shifts.

Two forces, mechanical wear and electrical erosion, are constantly at work destroying electrode materials and contours. The constant battering of electrode tends to forge them into abnormal shapes. Electrical erosion eats into the surface of the electrodes causing pits and oxidation. Proper balance between electrode pressure and current settings along with proper cooling and material application will reduce the effect of these two forces.

Die or electrode design for projection welding, particularly where an assembly must be nested, should incorporate large flat surfaces. Where it is necessary to reach into small areas, insert sections which are quickly replaceable should be used as shown by Figs. 11 and 12. This adds another mating surface into the electrical circuit so care must be used, both in design and in maintenance afterward, to be sure that the joint remains clean and tight.

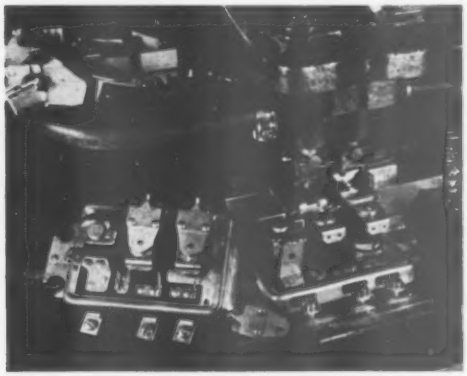

Fig. 10 Equalizing electrodes designed for rapid replacement

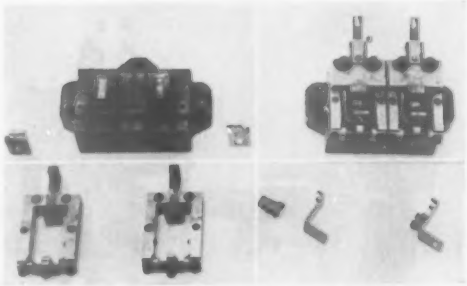

Fig. 11 Fixture for welding tab to bracket showing replaceable parts

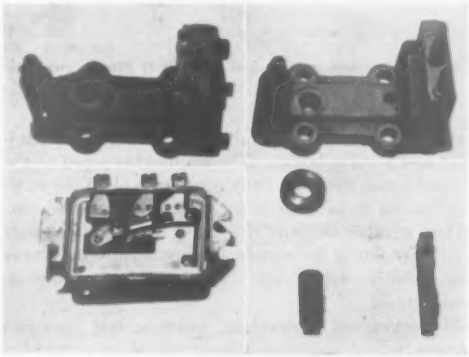

Fig. 12 Fixture for welding resistor into the regulator base, showing replaceable parts

It is important to note that properly designed electrodes, as well as other parts on the welder, seldom fail suddenly. Failure is usually a gradual process which should be stopped before completed. This can be done by periodic inspections and observation by qualified personnel. It will result in scheduled preventive maintenance rather than breakdowns.

One of the most important principles in regard to welder service is that of a unitized system of design. Mechanical parts, electronic controls and many other parts are grouped together so that, with a minimum amount of downtime, a complete device can be removed from the machine and replaced by a repaired and checked unit. Figure 13 (*A*) shows a complete welding head which can be removed by taking out two clamping bolts, two bolts holding the secondary bands and breaking quick unions in two air and water lines. The ejector shown in Fig. 13 (*B*) is of similar construction. After changing such units with the machine back in production, the replaced unit can be given a thorough overhaul and put back into serviceable condition. Thus the service technician is not under the kind of pressure that causes him to slight the job or use unorthodox repair methods just to get production moving.

For several years manufacturers of air equipment have

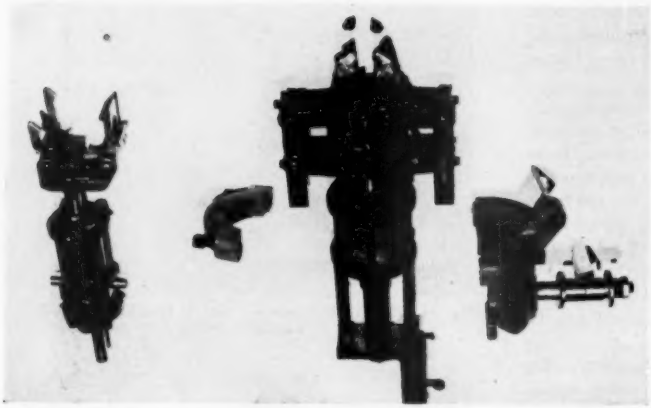

Fig. 13 Unitized mechanical parts: (A) Pincer gun head; (B) ejector mechanism

been making two-piece valves, consisting of a manifold and a valve body. The manifold is piped to the machine, and the valve body containing all of the valve mechanism is held to it by means of a few screws. When a valve becomes defective, it is not necessary to disturb any of the plumbing; just remove the screws and defective valve body, then put a new one in place and tighten.

The electrical connections, however, had been forgotten thus necessitating the services of an electrician for each valve change. Due to the research which prompted this report, our plant and at least one reputable manufacturer of resistance-welding equipment have started installing twist lock plugs on each air valve with an outlet box and receptacle to make electrical connection to the machine control circuit (Fig. 14). With this arrangement men with skilled classifications are not required to make a valve change. The operator, if necessary, can change a valve and be back into production in less than five minutes, providing spare valves are available. Defective valves can then be sent to the Maintenance Department for repair and checking by skilled men.

Timing equipment, since the advent of electronics into the resistance welding field, has been the bug-a-boo of maintenance personnel. It is, without a doubt, the most complicated phase of the welding machine. It is also the most often blamed for trouble simply because it is the least understood. Therefore, any system which would allow a quick interchange of timing equipment would offer many advantages.

1. Downtime, because of faulty timer operation, can be reduced by substituting spare units.
2. Maintenance personnel are allowed to work without pressure from production departments.
3. The investment in spare timing equipment is reduced to a minimum since all units are interchangeable.
4. New timers with technological improvements can be quickly checked without the cost of a permanent installation.
5. Allows trouble shooting by substitution.

Early timers had no provision for quick changing. Then, timers with most of the control circuit arranged on a plug-in front panel were introduced and greatly aided the advancement of resistance welding. Finally some manufacturers have started to make complete timers of the plug-in type. This is the ultimate as far as individual manufacturers of timing equipment are concerned. However, it is not possible for a user to purchase new equipment for all of his welders in order to take advantage of new and improved models as they appear on the market. On the other hand, he must not standardize on older timers or he will miss many advantageous improvements. As a consequence, it is easy to accumulate a wide variety of makes, models and types of timers. Each must accomplish the same job, namely:

1. Operate an air valve or trip a clutch to bring the electrodes together.
2. Turn the heat on and off at specified intervals.
3. Release the electrodes.

Each different weld sequence timer may accomplish these operations in a different manner. The fact remains that the manner of accomplishment is immaterial. Each weld sequence timer, whether it be in a combination panel or in a separate enclosure, has terminals to be connected as follows:

1. Two for incoming power.
2. Two for operation of the solenoid valve.
3. Two or four for operation of the welding contactor.
4. Two for operating heat on-off safety.
5. Two for pressure switch connections.
6. Two for initiation switch connections.

Therefore, as far as wiring weld sequence timers to a

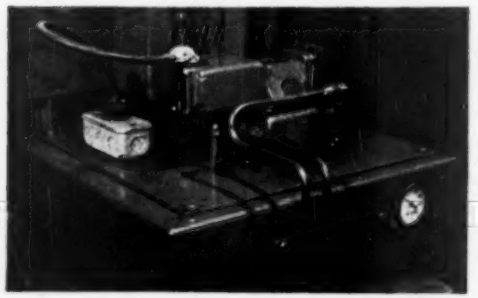

Fig. 14 Plug-in connections to solenoid-operated air valve

FUNCTION	RELAY FIRING PLUG TERMINAL	TUBE FIRING PLUG TERMINAL
Power	1	1
	2	2
Initiation	3	3
	4	4
Solenoid Valve	5	5
	6	6
Firing Contacts	7	7
	8	8
Heat On-Off Safety	9	9
	10	10
Pressure Switch	11	11
	12	12
Additional Firing Contacts		13
		14

Fig. 15 Table showing plug connections to weld-sequence timers

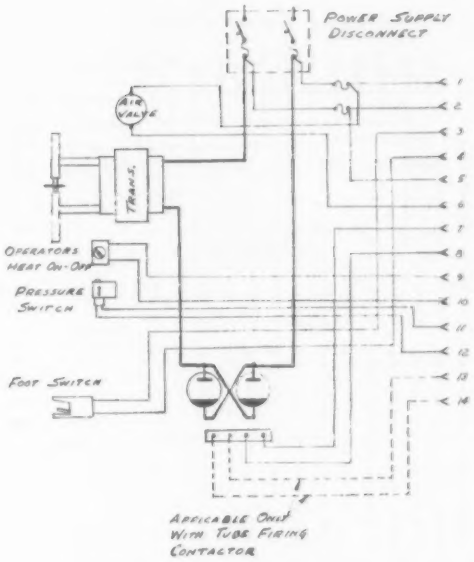

Fig. 17 Diagram showing female plug connections to a welding machine

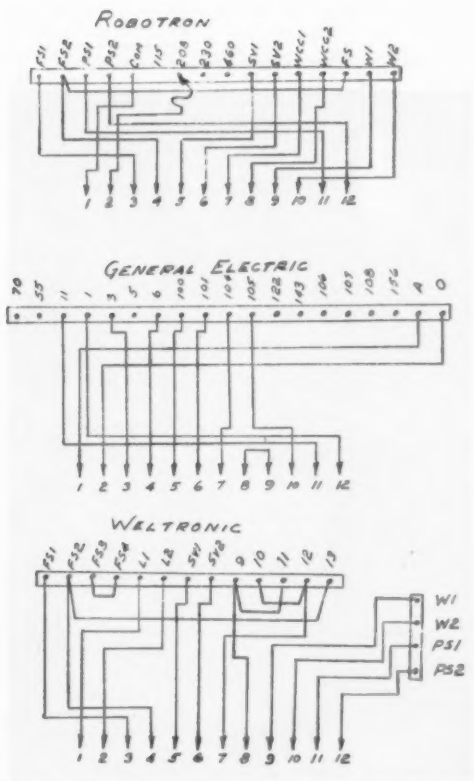

Fig. 16 Diagram showing male plug connections to various types of weld-sequence timers

machine is concerned, the only difference between makes, models and types is the arrangement of the terminal strip. The National Electrical Manufacturers Assn. has specified the functions of weld sequence timers; we propose terminating these functions to a standard male plug as illustrated in the table, Fig. 15, and the diagram, Fig. 16. Each resistance welder, consisting of the welding machine, solenoid valve, welding contactor, various switches and the power supply, is wired to a standard female plug (Fig. 17). Then matching any timer together with any welder will allow proper operation. A spare timer for each make, model and type is not required since any timer available will operate any resistance welder in the shop.

As with most systems there is at least one exception to the rule. This system is based upon the use of ignitron contactors which contain internal rectifiers. They require only closure of a relay or firing of two thyratrons, connected in inverse parallel, for operation. Some ignitron contactors, however, do not have internal rectifiers and require rectifiers inside the timers or a separation of the firing thyratrons so that each one fires a specific ignitron. This, however, does not impose a serious limitation upon the system. As shown in the table, Fig. 15, two more contacts are needed on the plugs connected to this type of welder. Each tube firing timer is likewise equipped with a plug having two additional contacts. Figure 18 shows the timer connections and the dotted lines in Fig. 17 show the two additional connections to the tube-firing ignitron contactor.

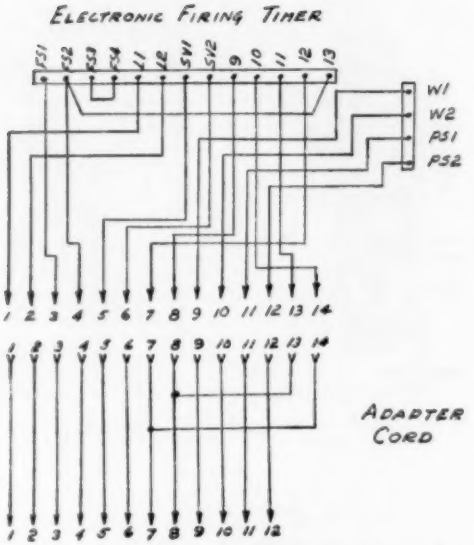

Fig. 18 Diagram of male plug connections to a tube-firing weld-sequence timer and adapter

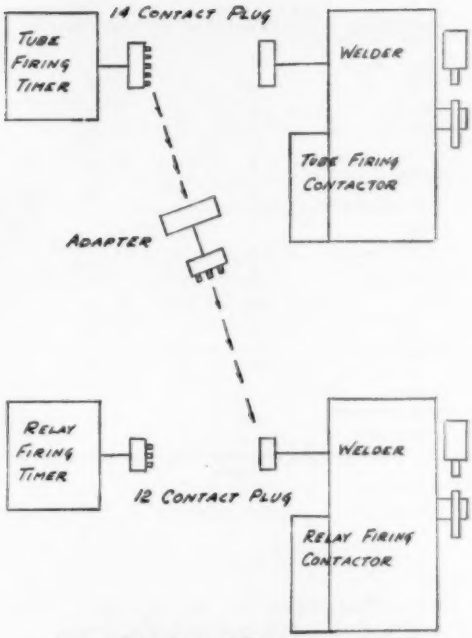

Fig. 19 Interchangeability of plug-in timers

With a 14-contact plug on tube-firing welders and a 12-contact plug on relay-firing welders, it is impossible to get a relay-firing timer matched to a tube-firing welder. However, it becomes necessary to keep two kinds of spare timers in the shop. It is not possible to use a relay-firing timer in place of a tube-firing timer since internal rectification is required. However, the reverse situation is possible. By connecting the tubes in inverse parallel a tube-firing timer can substitute for a relay-firing timer. This was done by using an adapter plug as shown in Fig. 4. The 14-contact plug on the timer is thereby reduced to a 12-contact plug by connecting wire 13 to 8 and wire 14 to 7. This places the 2-contactor firing tubes in the timer in inverse parallel as required.

The situation then stands as is shown in Fig. 19. If a relay-firing timer is used as a spare, it will operate only welders of the relay-firing type. But, if a tube-firing timer is maintained as the spare, it can be used on either type of machine. This, of course, would be the logical type of timer to keep on hand as a spare.

Figure 20 shows the system in operation. This welder has a defective timer so a special cart, having a spare timer on the lower shelf, is moved into position. The timer on the machine is quickly disconnected by breaking the plug connection. The machine is then plugged into the spare timer using an extension cable and immediately resumes operation.

The timer on the machine is thus entirely disconnected from all control switches and voltages. Figure 22 shows a wiring diagram of a test panel which is built into the lower front section of the cart. The defective timer is plugged into this test panel and can be operated

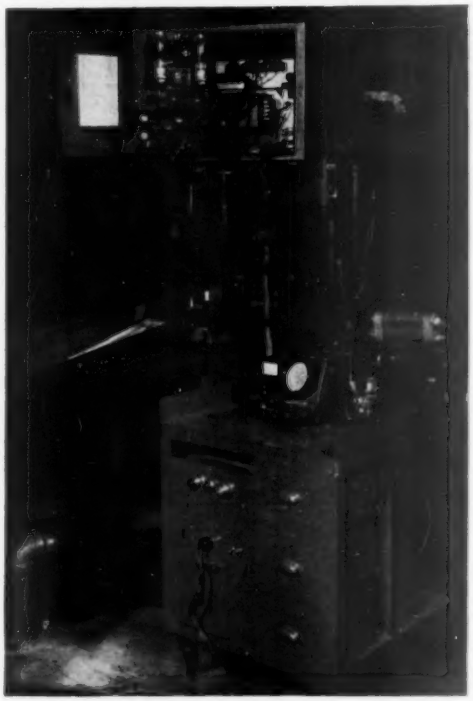

Fig. 20 The plug-in, weld-sequence timer substitution system in operation

for test while the machine is making production by using the spare. If the trouble cannot be found readily, the defective timer can be easily removed since it is entirely disconnected by the plug. Only after the timer has been repaired and thoroughly tested is it necessary to again interrupt production, and then only long enough to break the plug to the spare timer and make connection with the original, a matter of only a few seconds. Figure 21 illustrated diagrammatically the layout pictured in Fig. 20.

Isolating troubles in resistance-welding equipment quickly and efficiently is a job for one who thoroughly understands resistance-welding processes and equipment. He must also be familiar with the use of instruments, some of which are peculiar to the welding field. He must understand and be able to check electrical circuits, plumbing for air and hydraulic units, as well as mechanical devices. Often troubles occurring in resistance welders appear to be in one phase but are found in another. One very common example is the case of expulsion which shows up as sparks. The trouble may be diagnosed as improper timing, but very often turns out to be lack of pressure due to leaking seals in the air cylinder.

Most Maintenance Departments are divided into classified sections such as millwrights, plumbers, sheet metal, electricians, etc. This normal division does not lend itself to efficient trouble shooting in the resistance-welder field. Symptoms, in many cases, are too vague for the production foreman or operator to determine the cause of defective operation. As a result, plumbers are often called when an electrician is needed. Confusion and long-delayed repairs are the result.

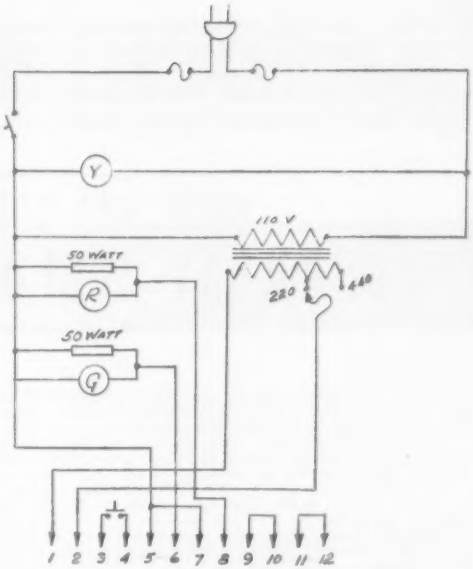

Fig. 22 Wiring diagram of timer test panel

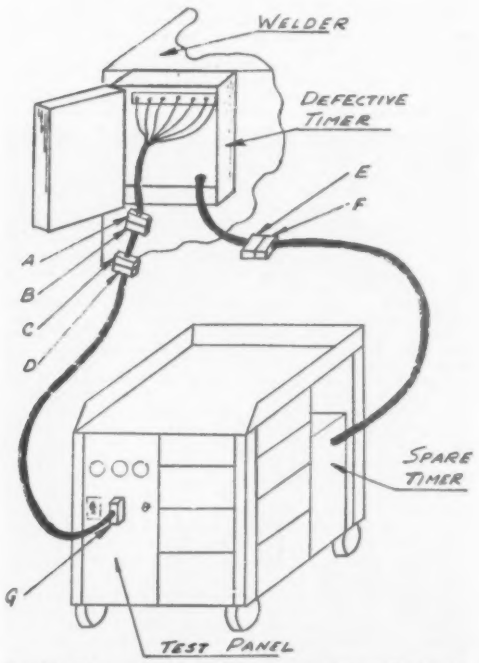

Fig. 21 Diagram of the weld-sequence timer substitution system in operation

One plan for avoiding this confusion and still not disturbing the classification of maintenance employees is to obtain or train engineers in this field. It is then their duty to check troubles as they appear and call upon the proper maintenance sections for repair work. It is also their duty to maintain contact with the work, making sure that it is efficiently accomplished, then finally to OK the job before it is placed back into production. In this manner downtime is minimized and no defective welds get into the production flow.

One engineer can handle several repair jobs simultaneously and, therefore, can supervise operation of a great number of welders. He can also be used to plan and assist in the installation of new welders, aid in development of new techniques and accomplish routine inspection of equipment. Whether or not a company is large enough and has a sufficient number of welding operations to warrant the services of a full-time engineer, some person should be made responsible for this part of the welding program. It will pay dividends in better welds and increased efficiency.

In conclusion, solving the maintenance problem has been attempted from many angles. Some are advantageous and have considerable merit. This report was not intended to cover them all but rather to point out a few basic facts from the author's experiences that have made possible a large reduction in resistance welder idle time. Proper cooperation between product and

production engineers as well as with equipment manufacturers is important in order to obtain the best equipment possible. Use of standard components and a unitized system of replacing defective parts speeds trouble shooting procedures. It gets trouble away from the production department and onto the repair bench where it belongs. Finally an engineer, thoroughly trained in all aspects of welding, will greatly facilitate the efficiency of any organization responsible for the operation of resistance-welding equipment.

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Some Body Repair Hints for the Shop

Fast repairs made with welding and cutting blowpipe

by C. E. Bland

AUTO body shops, like most modern repair shops, use the oxy-acetylene welding and cutting blowpipe as one of its most important tools.

The design of the present-day automobile, with large, costly body panels and fenders, makes replacement of damaged parts an expensive job. However, by cutting out only the damaged areas, and welding in new sections, repairs can be made quickly and economically.

Damaged sections of a panel can be cut out quickly with a cutting blowpipe and a new section from a spare panel welded in place. The remaining parts of the spare panel can be saved and used on other jobs.

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Fig. 1 Here a rusted strip is being cut out of a body panel with a cutting blowpipe

One shop cuts out the damaged section, then straightens and forms it and welds it back in place. This takes just a few minutes. When the weld is ground, smoothed over with body solder and painted, the panel is as good as new.

In welding or cutting work on automobiles, be sure that any flammable parts are protected. To keep from burning too much paint on the body, protect it with a paste made from asbestos cement and water. Apply the paste an inch or so beyond the weld line to protect the paint as much as possible.

SAFETY IS IMPORTANT

In automobile repair work, just as in any welding

Fig. 2 A replacement section is welded in place. Tack welds are made, then the final weld made

or cutting, it pays to observe the safety rules. Always keep a fire extinguisher close by, as shown in Fig. 1. Never weld or cut where sparks or an open flame would be a hazard. If you can move the work, take it to a place where you cannot possibly set a fire. If you cannot move the work, move all materials that burn easily a safe distance away from it. If you cannot move the work or the flammable materials, use guards to keep sparks close to the work you are doing. And above all, be ready to put out any fire promptly with fire extinguishers, water or sand.

Welding Simplifies Drilling Mast Construction

Charles O. Planting

IN MANY types of structural steel or iron work, welding is replacing the use of rivets, gusset plates and bolts during the fabrication process. In a large majority of cases, where a direct changeover to welding has been made, comparison with the older methods of mechanical joining gives welding a marked edge of superiority. Most important of these advantages are material and time savings. Other advantages accrue according to the nature of the product, and its use and handling during its service life.

Among the leaders to this switch to all-welded construction are manufacturers of oil field drilling equipment. As an example of this trend, International Derrick and Equipment Co., one of the largest concerns of its type, is now producing a full-view portable drilling mast in which welded joint fabrication plays an important role both production-wise and functionally.

These masts are simplified "A" frame structures, held in the upright position by a pair of auxilary legs which serve also as a part of the raising mechanism. The masts were designed to combine the advantages found in the standard drilling derrick with the lower cost of moving and rigging up offered by the drilling mast. An outstanding feature is the "full-view" principle, allowing drillers a maximum of unobstructed vision while on the job. Welding played an important part in making this accomplishment possible. Welding was also important in the design of the several high-strength joints incorporated in the unique mechanism used to raise the mast into drilling position.

Each mast is made up of a series of welded panels which are bolted to the next to attain the required height. It is evident that in this type of assembly, bolting is limited to the necessary breakdown joints, while the remainder of the mast exhibits the rigidity made possible by welded, monolithic construction. The same monolithic rigidity, with the addition of maximum safety, is attained by welding the various high-strength movable joints and attachment points used in raising, lowering and anchoring the mast.

Briefly enumerated, the chief advantages of welding in this type of structure, both production-wise and during use, have proved to be as follows:

Fig. 1 An IDECO full-view drilling mast goes up in the field. The tops of the auxiliary legs, visible near the base of the mast, are pulled downward along welded tracks by the rig's own traveling block. Thus, compression between the pinned leg bottoms and the welded track forces the mast into a vertical position. While this idea is as revolutionary as it is simple, it calls for the incorporation in the rig of high strength joints and pivotal points. Such joints are best fabricated by welding.

Charles O. Planting is Welding Engineer, The Lincoln Electric Co., Los Angeles, Calif.

Fig. 2 Partially welded panel section being repositioned by overhead crane. Note leveled I-beam structure on which components are positioned prior to welding. The accuracy of this structure imparts the same accuracy to the welded panel

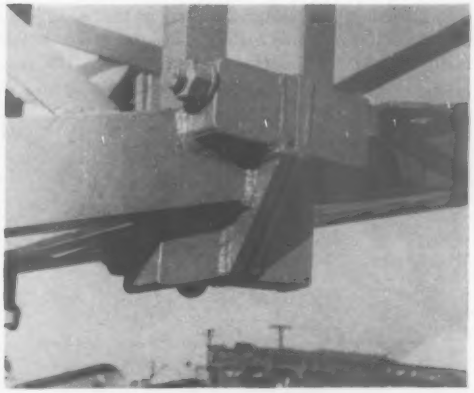

Fig. 4 Even though bolts are employed to fasten the mast sections together, the structure of these joints and the necessary faying surfaces is vastly simplified and strengthened by welding

1. Time savings that amount to approximately one-third during mast fabrication.

2. Material savings in the neighborhood of 20%.

3. Greater rigidity of the structure as a whole. The monolithic principle, made possible by welding, results in less vibration under working conditions, and less deformation during raising, lowering and hauling.

4. The welded construction results in smoother contours and better appearance and eliminates the various projections (such as bolt and rivet heads) which prove so objectionable during handling operations.

5. Welding, except for the necessary field connections between the major panel sections, definitely fixes breakdown points and prevents unnecessary disassembly during moves.

6. Pivotal joints and other joints that must operate under high loads can be simplified and be made lighter and stronger by welded construction.

A trip through the IDECO shops at Torrance, Calif., provides ample evidence of how welding simplifies mast construction. To begin with, the noise and clatter of numerous riveting guns is absent. Secondly, the clutter of piled gusset plate components and numerous rivet containers are noticeably absent. A minimum of operative tooling is required, with overhead handling equipment being in the majority.

The various structural components are flame-cut to size, using conventional flame-cutting equipment.

Fig. 3 The "cleanliness" of welded construction is clearly evident in this photo where several structural members of a full-view mast panel section come together. Try to visualize this joint area if gusset plates and rivets had been used

Care is used at this point to flame cut so that good joint fit-up will be obtained. Butt joints are used in the majority with lap joints where necessary. The material used is a low-alloy high-tensile steel with excellent weldability.

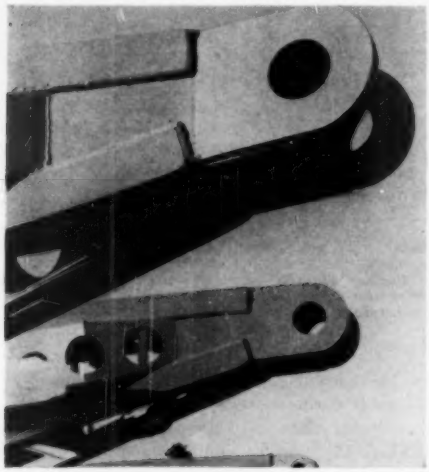

Fig. 5 Pivot joints at the bottom of each mast leg. These joints must withstand a terrific load during raising and lowering. The simplicity of welded construction is clearly evident

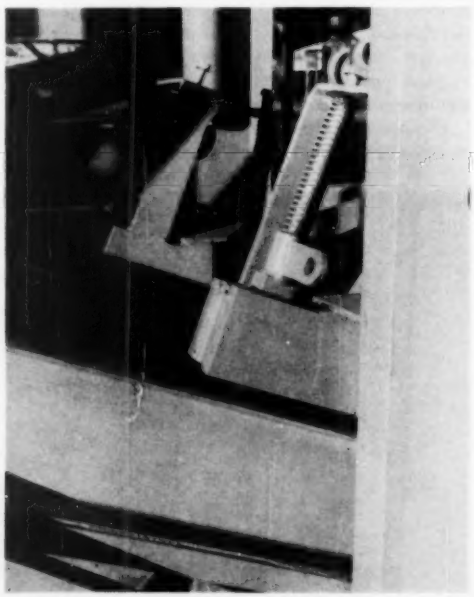

Fig. 6 These spring-loaded pawls are forced into a cam when the mast has reached the vertical position. The entire load of keeping the mast erect during storms or high winds is imparted to the adjacent area. Note simplicity of welded construction to give the necessary strength. This same area, fabricated using gusset plates and rivets, would be extremely complex

After flame cutting the various components are transported by overhead crane to their respective welding jigs. Conventional jigs are used for the small subassemblies. The jigs for the major panel components consist of heavy I-beam floor joist structures, plumbed and leveled, on which the structural components are positioned in a horizontal attitude. An overhead crane just above this I-beam floor structure is used for positioning.

All welding is in the flat or vertical positions with no overhead welding attempted. After all weld beads have been laid on one side of the panel structure, it is turned over by crane and the other side welded. One-pass welding is used exclusively on the mast proper,

Fig. 7 An IDECO welder at work in the crow's nest and crown block section of a quick-lift drilling mast

Fig. 8 View between two mast leg sections positioned on the ground. The same "full-view" characteristics prevail when the mast is in the upright position. The simplicity of welded construction aided IDECO engineers to attain desirable characteristic of the "full-view" mast

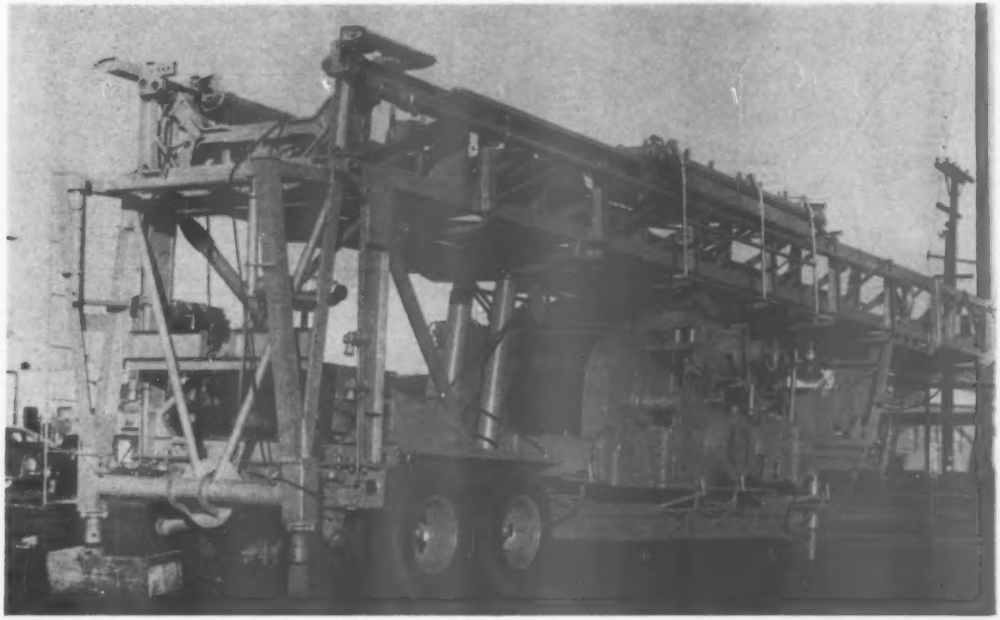

Fig. 9 Trailer, draw works, and quick-lift drilling mast, each of all-welded construction, ready for transportation to the drilling site

though two-pass welding is used in some instances on the sub-base which follows the usual pattern in structural assembly. The sequence of welding operations is carefully planned to minimize positioning in so far as possible.

After welding the various structural subassemblies are treated with a phosphoric acid solution to give them a corrosion-resistant coating. This prevents undue rusting before final assembly and painting. When required, certain of the weld beads are smoothed and finished by sandblasting. Thorough, visual weld inspection is given each part.

J. D. Thomas, IDECO's welding engineer, says that three types of welding rod are used, depending upon the subassembly and its requirements. These are AWS classifications E7010, E6016 and E6012. The bulk of rod used is E6012. About 150 lb of rod are required for each mast, and 200 lb for each sub-base. The sub-bases, like the masts, are of all-welded construction except for necessary breakdown points.

"Material and time-savings alone make welding a worth-while fabrication and construction technique," Thomas says. "Add these to the operational advantages that accrue, and it is quite apparent that welded construction, in so far as oil-field drilling equipment is concerned, will continue to gain favor."

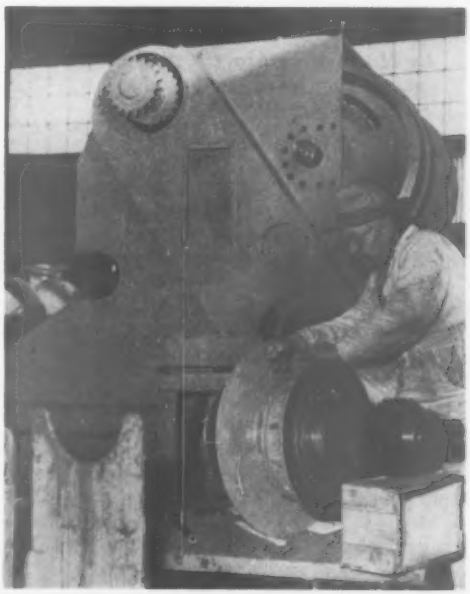

Fig. 10 View of draw works side panel fabricated entirely by welding. Note cleanliness of construction

Fig. 1 Center sill beams for gondola cars, comprising two Z-bar sections assembled in the fixture under the hoist hook

Z-bars descend the incline in the background for various stages of end welding; beams in the foreground are ready for welding on draft lugs, strikers, stiffeners and other components

All-Welded Steel Gondolas Built on Assembly Line

by Howard B. Martin and Michael J. Zevada

RAILROAD rolling stock, like box cars and gondolas, might not generally be construed as lending itself to assembly line manufacture because of its sheer bulk and weight. However, by skillful integration of steel-forming equipment, jigs and fixtures, manual and machine arc welding, positioners, overhead cranes and hoists, it has proved entirely practicable to the end that speed of assembly has reached a new high, and man-hour requirements per car a new low. Thus, important contributions have been made toward rapid reinforcement of the railroads' freight car fleet and toward meeting a goal of 10,000 new cars a month.

In the case of a recent order for several thousand low-type gondolas of all-steel welded design for the Pennsylvania Railroad, the job was broken down into various basic components—side plates and stakes, bolsters, center sill, cross bearers, strikers, etc.—and a fabricating setup worked out for each so that the finished subassembly could be fed to a central assembly line. On this line are 17 "stations" through which the gondola passes during progressive stages of assembly, the last nine of which are "on track"—that is, the car body is carried on its two trucks down a central track, being lifted off to one side or the other to complete the sequence of welding operations involved.

Each car requires a total of approximately 2600 lineal feet of welding, including both manual shielded arc and automatic hidden arc machine welding—some of the latter being done with tandem electrodes at speeds about twice those normally used with automatic welding.

The center sill is the backbone of the gondola structure, carrying the entire weight above the trucks and absorbing heavy longitudinal impact loads from the couplers at each end. The sill beam comprises two Z-26 car-building sections with vertical webs $^{15}/_{32}$ in. thick and about 13 in. deep, upper flanges $^{15}/_{32}$ in. thick and 7 in. wide and lower flanges $^{13}/_{16}$ in. thick and about 4 in. wide.

Upper flanges are turned in and their edges are welded together over their full 54-ft length. The resulting beam is actually a deep channel with outturned flanges at the open face, making a hat section. Although the beam has high strength and stiffness, it is reinforced at highly stressed points by welding on various other elements of the car underframe.

After the Z-bars for the sill are cut to rough length, they are pierced with the necessary holes and delivered

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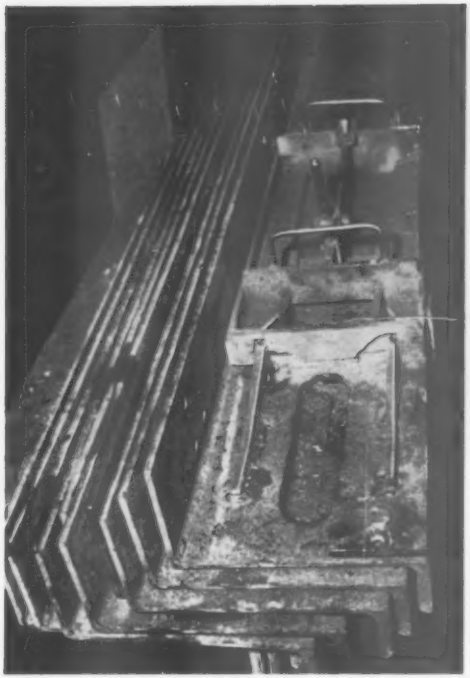

Fig. 2 Z-bars for center sills at the top station of the incline referred to in Fig. 1

Basket fixture shown is for locating a draft lug. Manual arc welding with coated mild steel electrodes is used in this work

to the top of a pair of inclined supporting beams, Fig. 1. Initial hand-welding operations near the two ends of the sill beams are made by operators working on a series of platforms which constitute two short flights of wide steps bringing the men to convenient positions relative to the work. Welding starts at the highest position and, when completed, stops holding the beam are removed and it is slid down the incline to the next position. Welding is done at each of four levels and it is unnecessary to do any lifting of the pieces until they reach the final or lowest position.

Welders work in pairs, one at each end of the beam, doing the same job at each end. At the top station, Fig. 2, draft lugs, located by basket fixtures, are welded in place, the fixtures being spaced correctly by a long pipe gage. At the next lower level, a key slot liner or flange of U-shape is placed in the elongated hole shown in Fig. 2, located by a fixture from below and welded around its outer contour to the web. At the same station a rear draft lug also is welded in place. At the third level stiffening ribs are attached. Most of these manual welds are made with heavily coated mild steel rods of E-6020 or E-6012 designation. On the heavy rear draft lug a rod with low-hydrogen coating, Lincoln LH-70, is used for greater penetration, strength and impact resistance.

At the fourth level the beam is turned over and the same operations are done as at the third level, repeated on the opposite side. Fixtures to facilitate rocking to the best welding position and for turnover are provided where needed. Some corner welds are made after the beam comes off the incline. A hoist is provided to lift the beam to permit cleaning off any welding slag and to transfer it to the seam welding fixture, Fig. 3, where two beams are placed together to form the sill section.

Fig. 3 End view of clamping fixture in which a pair of Z-bars is positioned with seam over the copper backing strip for hand arc welding

Completed center sills are shown at the right. Lincoln manual hidden are welding units for welding inside seam are suspended from trolleys overhead

Dovetailed to the longitudinal top plate in this fixture is a copper backing strip that is centered below the edges of the flanges to be welded once they are locked in position. The top plate is supported by a heavy I-beam. Clamps are air operated and when locked into place, press the flanges tightly against the backing strip. Three screw-operated shoes, one at the center and two midway between the center and the ends are adjusted to give the beam sections a specified upward camber of 7 1/2 in. after clamps near the ends pivoted to the floor structure are fastened.

Side clamps also press the edges of the flanges together and the outside width over the vertical welds is gaged before welding starts. As the edges are not perfectly straight, they do not meet throughout their

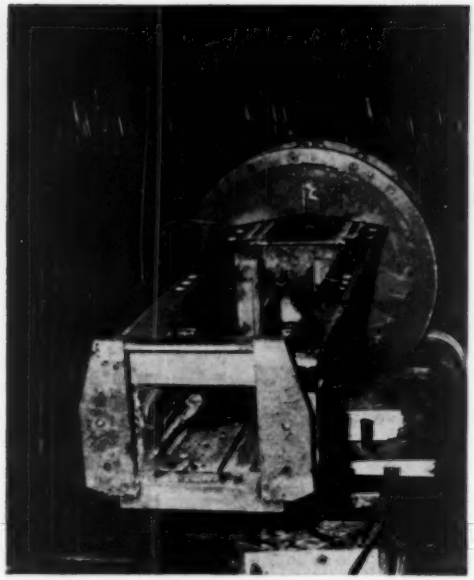

Fig. 4 Center sill in roll-over fixture where striker plates are arc welded to each end after center fillers, one of which appears just inside the split turnover ring, have been welded into place

length. This fact, together with the need for maintaining camber, has not lent itself to the use of fully automatic machine welding setup for making the longitudinal weld, although efforts are being made to work out such an arrangement.

The external bead is laid manually by four welders, two starting at the ends and two at the center, working in opposite directions until they meet. Next the beam is turned over onto steel horses for the internal welds, using two Lincoln manual submerged arc units suspended from trolleys. (See top of Fig. 3.) These welds are not continuous, as they are required only at the bolsters, sill ends and cross bearers. Total length of the welds is 15 ft and penetration extends into the bead on the reverse side.

Longitudinal welding completed, torch cutters are used to notch the beam ends, as shown in Fig. 1, and fixtures are applied to locate strikers at the ends and to square up the assembly. Strikers are hand welded in place. A fixture likewise locates the center fillers, subassemblies previously built up by hand welding their various components. The fillers fit inside the beam and are tack welded in place before fixtures are removed. A number of center sill separators also are fitted in position at this stage.

A crane then transfers the beam to a rollover fixture, Fig. 4, the supporting rings being split so they can be opened to receive the beam. In this fixture, one welder works at each end, performing duplicate operations. The beam is easily rotated to any position about its axis so that effective down-hand welding can be done.

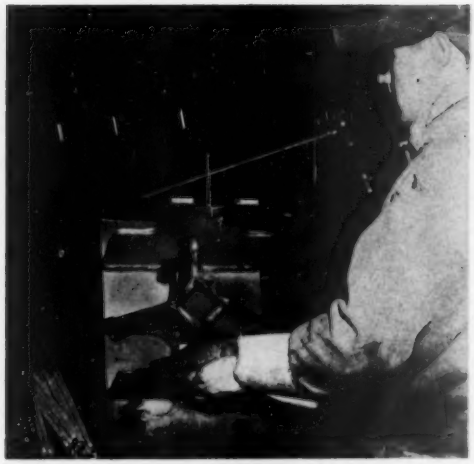

Fig. 5 Center filler subassembly is supported on an inclined pivot pin for arc welding the heavy plate components to the base plate

Strikers, center fillers, separators and other elements all are manually welded on both sides of every joint to complete the sill assembly. It is then touched up by grinders and is ready for the line.

Center fillers, Fig. 5, are built up from flat plate segments, two of which are cut to contour, and four formed plates to make the square central hole. Formerly this work was done on a stationary pivot which could be set at different angles, but it was awkward to make some joints because their levels varied and lifting had to be done, thereby slowing the job. A special

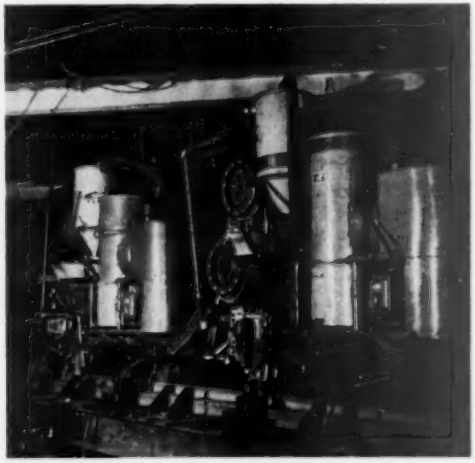

Fig. 6 Each of these two carriages mounts two hidden arc automatic welding heads, together with flux supply and recovery units

They automatically weld the joint in a pair of angles for a side stiffening rail. Two electrode wires are fed into each arc simultaneously. This tandem arc setup for laying a single bead permits speeds double those normally used

Fig. 7 Close-up of the tandem hidden arc welding head laying a bead in the angle assembly

Excess flux is retrieved and returned to the supply hopper. Heads are guided by a horizontal beam mounted on the wall columns of the plan

fixture was designed with a counterweight arranged so that the pivot can be raised or lowered easily and will remain set without locking The work also can be rotated about the pivot.

Seam welding the center sill sections, torch cutting to length and fitting the center fillers, strikers and separators, and operations in the rollover fixture, as just described, make up the first three major assembly "stations" and are actually of a preliminary nature. The point where the car begins to take shape is at the fourth station, a large jig in which four sections of bolsters, four cross ties at the wheels, ten cross bearer halves, eight cross ties at the center, 32 stringers, the center sill, brake cylinder support plate and brake rod and lever guides are all positioned and tack welded, ten men fitting and eight welding.

Before continuing on down the assembly line, it may be of interest to examine a couple of other unusual welding jobs—on Z-bars used for top rails of the gondola sides and on side plate assembly work. The Z-bar is made from two $3^1/_2$-x $^5/_{16}$-x 4-in. standard angles by arc welding two edges down the center of what becomes the web of the bar. Each angle is 52 ft long and the welding setup is shown in Fig. 6 with a close-up in Fig. 7. It is possible to make continuous welds with a total length of 120 ft in this machine which is set next to one wall of the shop and has the rail supporting the welding heads carried on brackets attached to the wall columns.

Along the bed of the machine are adjustable air clamps to lock the angles in place. One leg of each angle is horizontal, the other of one angle projecting upward and of the second angle downward. The machine is equipped with two carriages mounting automatic welding heads in tandem, each supplied from a coil of $^7/_{32}$-in. copper-coated wire. Each head operates off a 1200-amp, generator and incorporates a

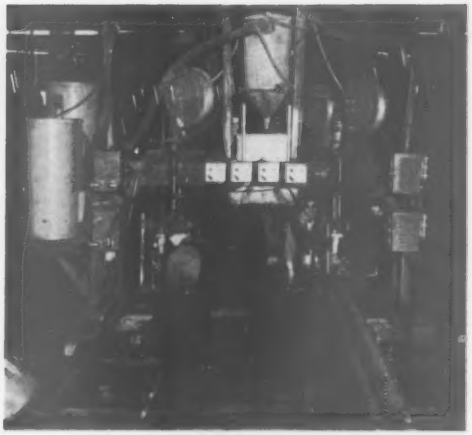

Fig. 8 Four automatic hidden arc heads in two tandem pairs are mounted on this carriage which moves longitudinally along the car side sheets, simultaneously fillet-lap welding both top and bottom rails to the sheet

flux feeding mechanism. Excess flux is picked up by suction and returned to the supply tank on the carriage. Travel during welding is about twice the usual automatic machine speed and is from each end toward the center of the fixture.

This rapid traversing makes it necessary to feed metal to two arcs in tandem in the pool. Hence, the two heads are set with electrodes about 2 in. apart, parallel to the joint and arranged so as to deposit metal simultaneously. Penetration of about 60% is obtained, so after laying one bead the bar is turned over and welded from the other side similarly.

Operation of the machine requires one welder and two fitters for each carriage, or a total of six men, but they produce four times as many Z-bars per shift as an equal number of manual welders could handle.

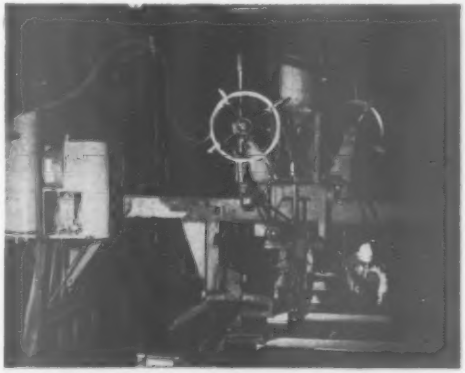

Fig. 9 Two welding heads on this carriage move across the side sheet to weld both sides of reinforcing stakes to the sheet. Clamps on either side spot the stakes accurately and hold them firmly

The speed of tandem automatic arcs is also used to advantage in making fillet welds which join both top and bottom rails to side plates or sheets, Fig. 8. Each side is 52 ft in length and 5 ft wide, made up of five 1/4 in. plate sections, automatically welded by hidden arc units across the seams to form the full side sheet. This is done while the plates rest on a roller conveyor. Traveling on down the conveyor, the sheet receives top and bottom rails which are clamped in position and manually tack welded before moving to the automatic machine which welds the full joint. The sheet is clamped to the bed of the machine, gages being provided to insure accurate positioning. A carriage supporting four welding heads, controls, wire reels and flux recovery units travels lengthwise over the sheet, making two 3/8-in. fillet welds simultaneously at speeds three times the usual automatic rate.

Thirteen hat section reinforcing stakes are welded automatically to the side sheet, equispaced along its length. This machine, shown in Fig. 9, is also a unit of the hidden arc type, with one head on each side of the stake, the latter being positioned accurately and held firmly by clamps on either side of the machine. The welding heads have offset wire feed jaws coming into the joints at approximately a 45-deg angle, as may be seen in Fig. 10. The side sheet with stakes in place moves on down the conveyor and 32 hold-down clips are manually welded along the upper edge. These are provided to receive straps used in dumping loaded gondolas in service. Finally the sheet is turned over and the bottom reinforcing rail or angle is manually welded with a continuous bead. The top rail is skip welded on the inside at 5-in. intervals.

Returning to the final assembly line, it should be pointed out that the underframe is fitted up in a jig in the inverted position, there being two jigs provided—one for fitting up and one for tack welding. The

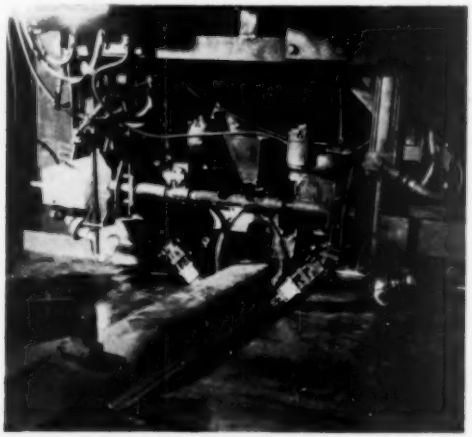

Fig. 10 Close-up of the stake welding operation showing how inclined electrodes are guided into the lap joints at about a 45-deg angle. Each side sheet has 13 stakes

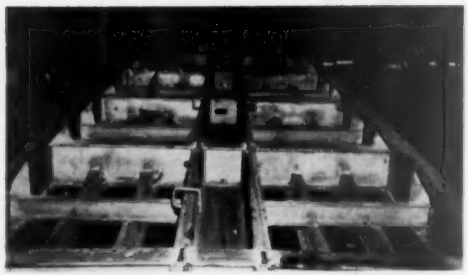

Fig. 11 Partially completed underframe on the final assembly line, showing center and side sills, cross bearers, cross ties, stringers and other components, all manually arc welded in a down-hand position

frame next moves to another jig setup for completing all bottom side welding; all welding being done in the down-hand position for maximum speed and penetration. Generators of 500-amp rating are furnished for each welder, this being true on down the line and in fact throughout the shop wherever manual welding is being done.

The next station comprises two positioners into which underframes are placed by overhead crane, being gripped at either end of the center sill so that the entire frame may be rotated about its central axis by means of electric motor drive at one end of the positioner. Center sill webs are welded on both sides, merely by turning the frame through 180 deg.

Still in the inverted position, the frame proceeds to a fixture for down-hand welding of two bolster cover plates, for fitting, tacking and welding two sole plates at the bolsters and for finishing any bottom side welding which may have been overlooked.

Next are two jigs where two body center plates, four body side bearings, draft gear and draft gear support are fitted. Since wear is likely on some of these parts and replacement will be required, assembly is by riveting, using an air-powered bull riveter.

Now the underframe is turned over, Fig. 11, and placed on its two trucks at station No. 9 where operators weld top cover plates and stringers on the top side. Floor support strips also are welded at the sides at this point.

Attachment of side sheet subassemblies follows. Steel pipe spacers are placed at intervals along the top edges of the sides, holding them firmly at 9 ft 5 1/2 in. apart. A pair of sides, with spacers attached, is lowered to the underframe and tack welded at the cross members. A row of 13 air cylinders on a framework at either side bears against the side stakes to position the side sheet for initial welding. An additional cylinder at each corner serves to raise the sides to proper height.

Succeeding operation, that of attaching corner posts and end assemblies, is a dual station, one on the track and one in positioners. End assemblies are lifted into place by crane and tack welded while the car is on track, five welders, six fitters and a burner being the crew. For final welding of the end assembly, the car

Fig. 12 At one of the stations on the final line, the underframe, with side plates attached, has been lifted from the trucks (extreme right) into a positioner which tilts it to this position for welding on side sill

body is lifted off the trucks and placed in positioners adjoining the track on either side, Fig. 12. After welding, the body is replaced on the trucks and moves ahead to the next station where it is again lifted off, Fig. 13, and set in positioners which turn it 90 deg for welding cross members and corner posts to the sides.

At station No. 13 are two more positioners flanking the track, in which opposite sides to those welded in No. 12 are completed; this again to allow all welding in the down-hand position. At this point the car body is turned upside down for remaining underside welds, the only time in the assembly process where sides are in the inverted position.

Fig. 13 With welding operations completed at this station, the car body is swung back to its normal position and moved over onto waiting trucks to be rolled down a track to the next station

Fig. 14 Nearly ready to roll, the gondola gets finishing touches by a welder working on corner posts at the final assembly line station

Following operation provides for welding reinforcement members to the center sill, welding subend sill to the center sill web, fitting the couplers and taking out spacer bars between the sides.

Next comes installation of grab irons and standard safety appliances.

At No. 16 while on track, corner gussets are welded to sides, corner posts to subend sills, door trunnions to the end sill, and end stringers to the bolster center plate and end sill.

Finally, at the O.K. or No. 17 station, Fig. 14, four welders are on hand to correct anything caught by inspectors and to complete minor tasks like welding side plate extensions to corner posts and side plates, to attach corner post caps, etc. The car then is ready to roll, after end doors are installed, the latter being another welded subassembly and readily fitted into trunnions on the car.

From the foregoing it is readily apparent to what a large extent welding has taken over from the former practice of riveting in freight car manufacture. When the job was rolling at peak rate, electrode consumption was close to 8000 lb of $^5/_{16}$-in. rod per day, and no stubs longer than 2 in. were tolerated, according to signs posted prominently around the shop.

Contrast in the noise level with old car-building methods where dozens of riveting hammers were clanging incessantly is striking. Noise has been replaced by the blue-white flame of the welding arc and the hum of the submerged arc machine traveling effortlessly along a seam. They serve at once to make working conditions less nerve-wracking, to speed up assembly operations and to effect lower over-all costs.

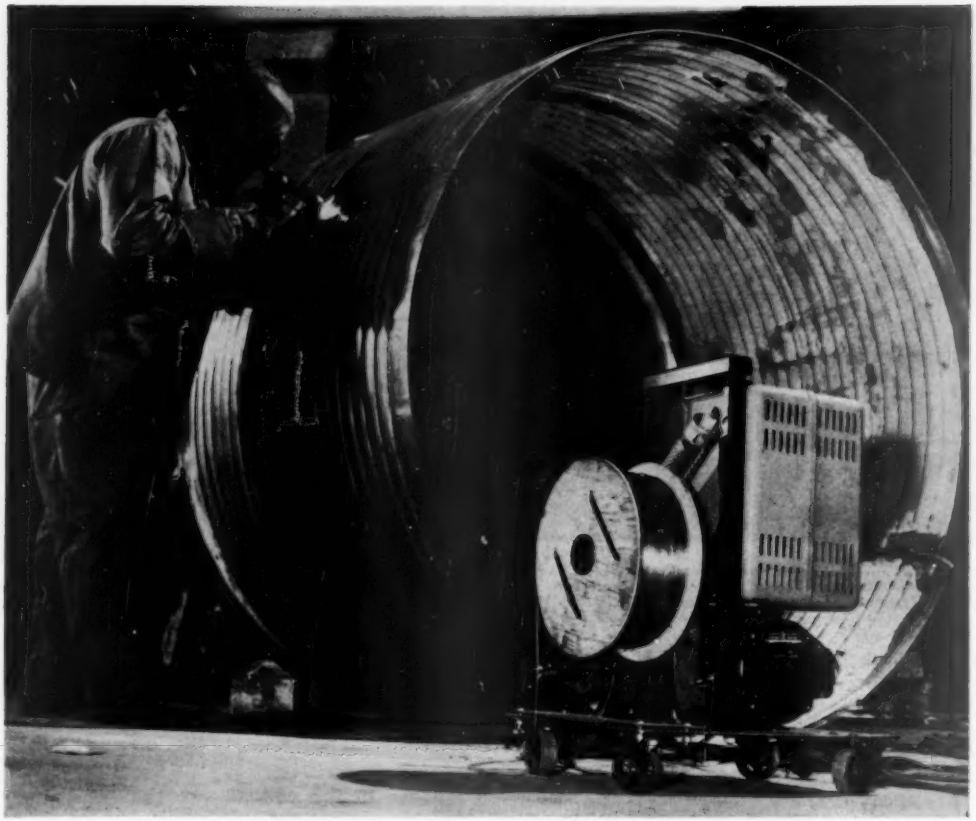

Fig. 1 Operator at the Cherry-Burrell Corporation, Little Falls, N. Y., uses an Inert-Arc welder to weld on the lining for a processing vat. The vat is used for milk-mixing, as well as for mixing other substances heavier than milk such as buttermilk, ice cream, and chocolate milk. The G-E Fillerweld equipment, shown in foreground has allowed a 30 to 50 per cent reduction in finishing costs at Cherry-Burrell

Cutting Finishing Costs

A 30 to 50% reduction in finishing costs has resulted through the use of General Electric Fillerweld inert-arc welding at the Little Falls, N. Y., plant of the Cherry-Burrell Corp.

Because the firm manufactures stainless-steel coolers, processors, farm tanks and pumps to precise sanitary and engineering specifications, finishing operations have traditionally accounted for two-thirds of its fabrication costs.

The adoption of the new machine has allowed the firm to eliminate nearly half of these finishing costs. The new type welder allows the operator to control a continuous flow of filler-metal automatically by means of a finger switch mounted on the torch, producing a smoother, less metal-consuming weld.

Prior to the adoption of the new welder at Cherry-Burrell, the fabrication was done with conventional metal-arc welding equipment. Considerable excess metal, added to each weld, had to be removed with a 36-grit grinding wheel and the weld polished with a 90-grit wheel.

According to Robert F. Mager, process engineer for Cherry-Burrell, "The use of G-E Fillerweld has reduced excess metal to such an extent that our finishing now usually starts with the 90-grit wheel."

In addition, Mr. Mager said, welds on sanitary vessels must be free from porosity and pinholes. When pinholes have to be filled after the polishing operation, it results in additional finishing expense. "The new welder leaves almost no pinholes," he said.

Designed to be used with gas-shielded arc welders, the Fillerweld gun is basically a manual water-cooled inert-arc tungsten holder to which has been added a control switch and a gear assembly for pulling the filler-metal from the spool to the arc through the gun.

To operate the new equipment at Cherry-Burrell, the operator merely presets the desired filler-wire speed by means of a rheostat and then strikes the arc as though it were a normal inert-arc torch. As soon as a molten pool has been established in the base metal, he pulls the trigger on the gun and the wire feeds into the arc. To stop the wire feed at any time, even during welding, he has only to release the trigger.

Rated at 250 amp, the gun accommodates tungsten from $^{4}/_{100}$ to $^{5}/_{32}$ in. in diameter and up to 7 in. long. It can be used with either argon or helium.

Elements of Weld Design

◗ *How efficient use of materials can save 50% on cost*

IN THE examples below, the engineer has designed a stronger, more durable machine part by the intelligent use of a less costly material. While increasing product rigidity 100%, he has reduced material costs 83%. At the same time, he has achieved an ultimate reduction in cost from $1.52 to $0.75, representing an over-all saving of 51%.

The savings effected on this typical machine part can be readily attained on a broad range of manufactured products in essentially every type of industry today.

This paper is one of a series prepared by The Lincoln Electric Co., Cleveland, Ohio.

The individual cost reductions on any one part or group of parts depends largely on the creative ability of present-day designers to get the most service from each pound of metal, as well as from each man-hour involved in the fabrication of the part as shown in the following engineering study.

By proper designing and use of welded steel, it is possible to cut manufacturing costs by 50% or more. The graph (Fig. 2) shows how these savings are achieved. Compared with gray iron costs at 100%, simple duplication of size and shape in steel reduces material costs to 35%. This initial saving is possible because of steel's lower cost per pound.

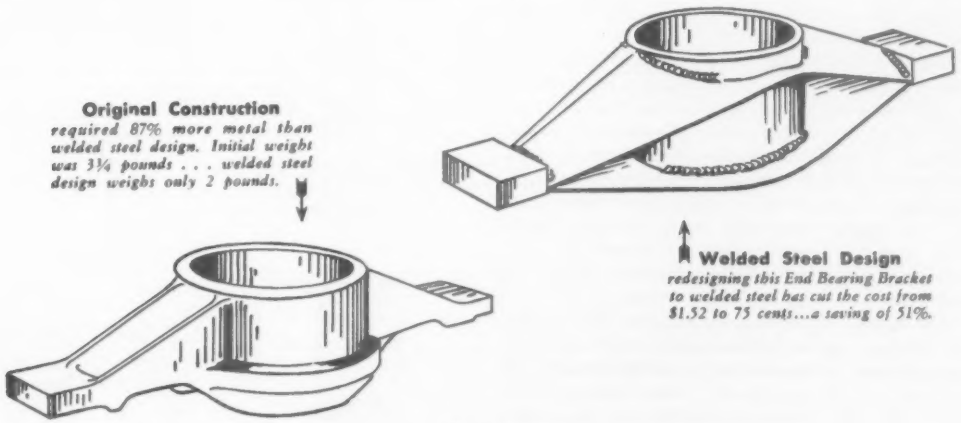
Original Construction
required 87% more metal than welded steel design. Initial weight was 3¼ pounds . . . welded steel design weighs only 2 pounds.
Welded Steel Design
redesigning this End Bearing Bracket to welded steel has cut the cost from $1.52 to 75 cents...a saving of 51%.

Figure 1

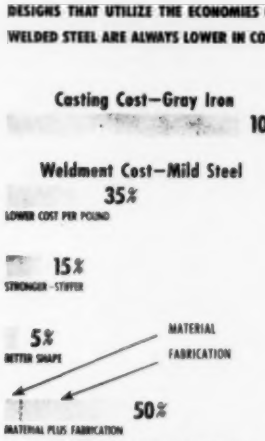

Figure 2

When the greater strength and rigidity of steel are fully utilized, material costs can be reduced to approximately 15%. Ultimately, the use of better engineering shapes, made by forming steel, often reduces material costs to as low as 5% of original gray iron requirements. With such initial material savings on which to base his design, the engineer has a latitude of 35 to 45% for actual fabrication and still realize cost reductions of 50%. Whenever weldment costs do not follow this yardstick, the designs generally are falling short of the full economies of welded steel construction.

The basic design principle underlining the efficient use of metal in many products is, of course, to concentrate the materials as far away as possible from the center or neutral axis of any load-carrying member. With this procedure, greater loads can be carried safely with less metal. As can be seen in Fig. 3, the progressive transfer of material from the center to the outer edges permits the use of thinner wall sections. In the ultimate designs, sheet metal can actually be used, further cutting the weight and production cost.

When establishing any design for manufacture, such factors as quantity of production and type of equipment for fabrication, of course, influence the final construction details. As in the case of the alternate designs in Fig. 3, these factors logically determine which of the five designs would be adopted. With the endless combinations of design details available with steel construction, the engineer can design close to his shop equipment and also make progressive improvements in details at low cost as production quantities increase and additional fabricating equipment become feasible.

The simplest fabrication is with plain flame cutting and welding. As quantities increase, brakes and bending equipment are economical for speeding production and cutting down labor costs. Where high quantities are involved, dies become justified to form components to eliminate joints and reduce the amount of welding.

The progressive redesign of the bracket shown in Fig. 4 illustrates how a structural machine member can be modified for efficient, low-cost fabrication. Here again, every effort is made fundamentally to concentrate materials at outside edges for maximum load-carrying capacity. For the shop with simple shears and bending brake, the components are cut from light plate, holes drilled or punched and the assembly welded in a simple fixture. The next design shows a similar bracket except designed for the shop with only flame cutting and welding equipment. An ordinary tee section is flame cut or hack-sawed, bent and welded in an inexpensive fixture. The final design shown achieves perhaps the ultimate in efficient use of materials as well

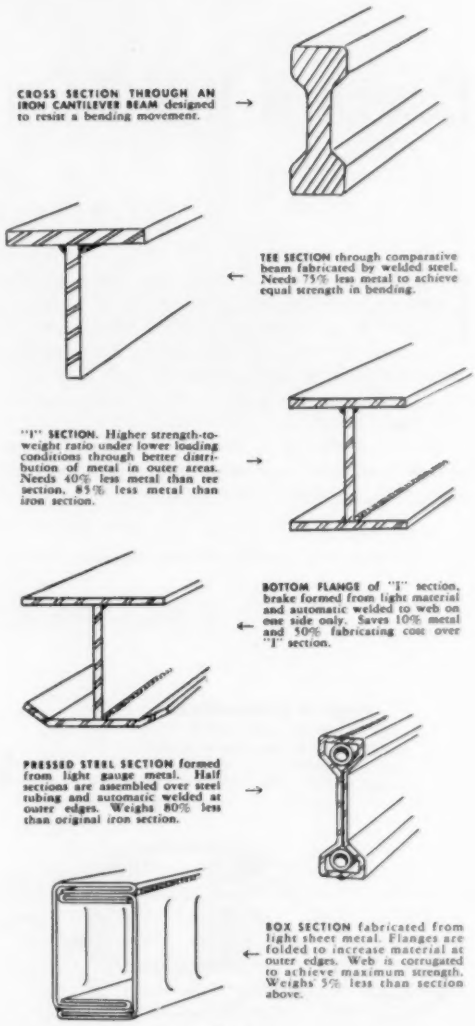
CROSS SECTION THROUGH AN IRON CANTILEVER BEAM designed to resist a bending movement.
TEE SECTION through comparative beam fabricated by welded steel. Needs 75% less metal to achieve equal strength in bending.
"I" SECTION. Higher strength-to-weight ratio under lower loading conditions through better distribution of metal in outer areas. Needs 40% less metal than tee section, 85% less metal than iron section.
BOTTOM FLANGE of "I" section, brake formed from light material and automatic welded to web on one side only. Saves 10% metal and 50% fabricating cost over "I" section.
PRESSED STEEL SECTION formed from light gauge metal. Half sections are assembled over steel tubing and automatic welded at outer edges. Weighs 80% less than original iron section.
BOX SECTION fabricated from light sheet metal. Flanges are folded to increase material at outer edges. Web is corrugated to achieve maximum strength. Weighs 5% less than section above.

Figure 3

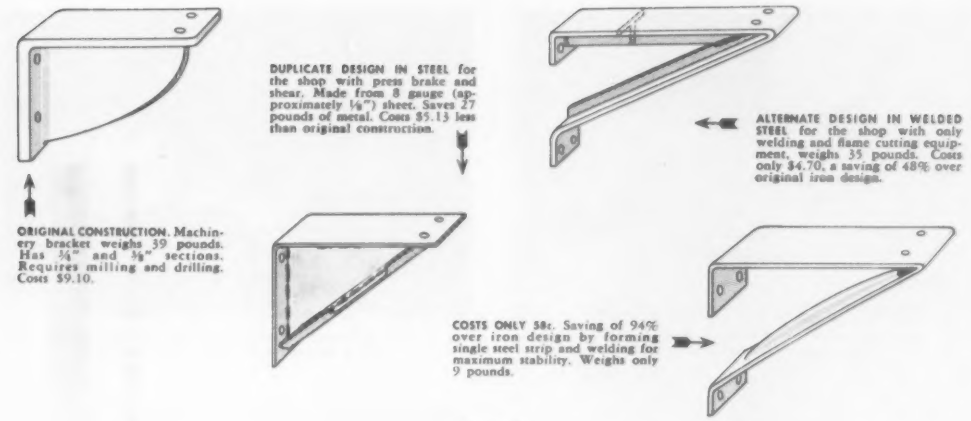
ORIGINAL CONSTRUCTION. Machinery bracket weighs 39 pounds. Has ¾" and ⅝" sections. Requires milling and drilling. Costs $9.10.
DUPLICATE DESIGN IN STEEL for the shop with press brake and shear. Made from 8 gauge (approximately ⅛") sheet. Saves 27 pounds of metal. Costs $5.13 less than original construction.
ALTERNATE DESIGN IN WELDED STEEL for the shop with only welding and flame cutting equipment, weighs 35 pounds. Costs only $4.70, a saving of 48% over original iron design.
COSTS ONLY 58c. Saving of 94% over iron design by forming single steel strip and welding for maximum stability. Weighs only 9 pounds.

Figure 4

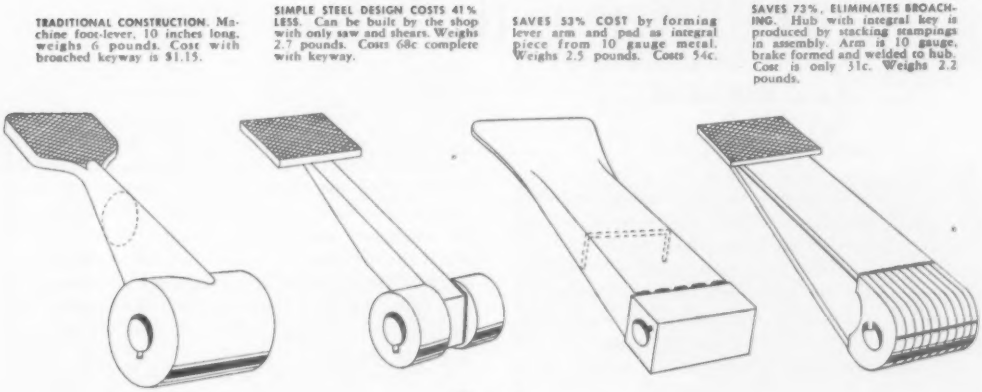
TRADITIONAL CONSTRUCTION. Machine foot-lever, 10 inches long, weighs 6 pounds. Cost with broached keyway is $1.15.
SIMPLE STEEL DESIGN COSTS 41% LESS. Can be built by the shop with only saw and shears. Weighs 2.7 pounds. Costs 68c complete with keyway.
SAVES 53% COST by forming lever arm and pad as integral piece from 10 gauge metal. Weighs 2.5 pounds. Costs 54c.
SAVES 73%, ELIMINATES BROACHING. Hub with integral key is produced by stacking stampings in assembly. Arm is 10 gauge, brake formed and welded to hub. Cost is only 31c. Weighs 2.2 pounds.

Figure 5

as lowest fabricating costs. A plain strap is die formed to reinforce the bottom or compression member, then bent and held in a fixture for welding.

An operating machine part like the foot lever in Fig. 5 needs maximum strength with minimum weight to reduce inertia forces as much as possible. Duplication of the original iron construction with steel cuts the weight from 6 to $2\,^{7}/_{10}$ lb. and manufacturing costs from $1.15 to $0.68. For larger quantities it becomes economical to form the arm from sheet metal, saving $^{2}/_{10}$ lb. of material. In the ultimate design, the hub, fabricated from stampings, incorporates an integral key and thereby eliminates the need for broaching and furnishing a key as needed in traditional construction.

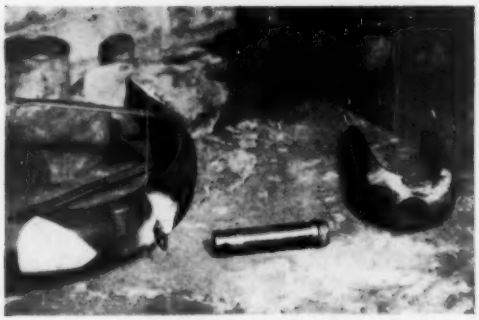

Fig. 1 Here the mudguard, fork and the stem have been taken apart for welded repair

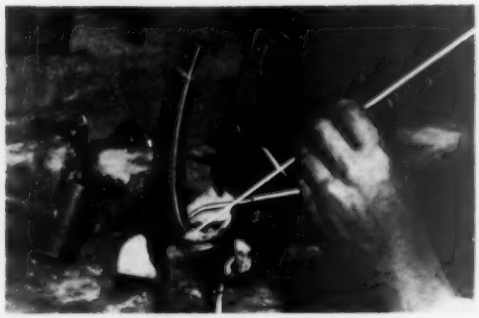

Fig. 2 The stem and the fork are now being joined. The weld is being made from the underside

Bike Repair in the Welding Shop

by A. Rothschild

JOBS come into the average welding shop that range all the way from large machine castings to a part from a washing machine. Repairing bikes and keeping them off the scrap heap is another of these jobs. In the hands of a healthy, active youngster, bikes and bike frames get dented, bent, and cracked.

Here are some actual jobs handled by a repair shop in Chicago. They are all fairly simple jobs and were done by braze welding. The low heat of braze welding makes it possible to repair parts of this kind quickly and easily and without causing any distortion or warpage to the metal.

A. Rothschild is connected with Art's Cycle and Hobby Shop, Chicago, Ill.

The first job, see Figs. 1 and 2, shows a stem that had broken away from the fork. The first step in this job was to remove the mudguard so that the welding repair could be made. The mudguard was removed by heating with the blowpipe. Because it had originally been braze welded, heat applied to the weld melted the bronze and the mudguard was easy to remove. Then the areas where the weld was to be made were thoroughly cleaned so that there would be good tinning. The braze weld was then made from the underside and when that weld was completed the final step was to weld back the mudguard to the fork.

In the second repair job the threads of a sprocket hole had been stripped and were built up and then rethreaded. This job is shown in Figs. 3 through 5.

First, the sprocket was laid flat and the hole thoroughly cleaned. Then the part was heated to a dark red

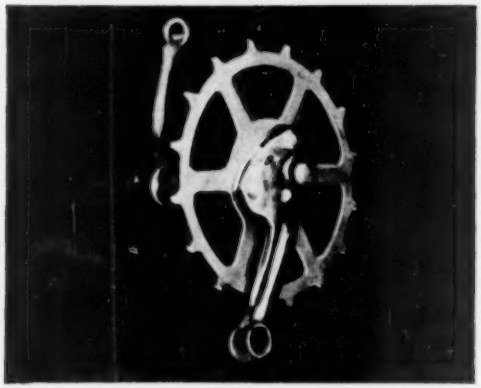

Fig. 3 The threads of this sprocket hole have been stripped and must be built up and then rethreaded

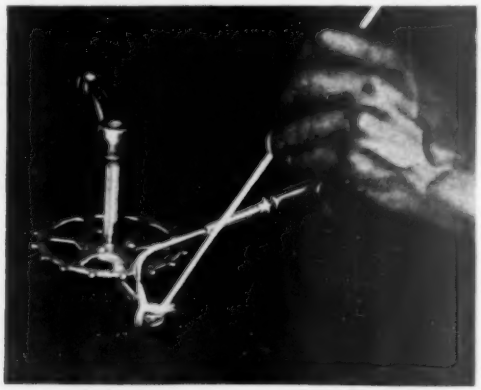

Fig. 4 The part is heated to a dark red and the hole is filled up with bronze welding rod

Fig. 5 Here is the filled hole. The next step will be to drill and rethread a new hole for the sprocket

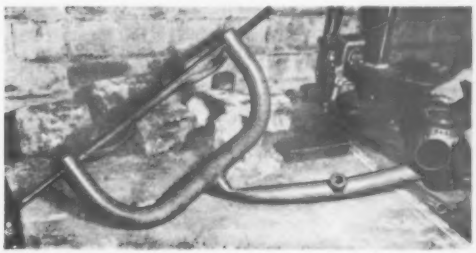

Fig. 6 This is another common job—a bent frame. First the frame must be cut apart and straightened

Fig. 7 Then a tubular insert about 1½ in. long is inserted into each end of the frame and the metal cleaned

Fig. 8 Tack welds are then made to hold the parts in position while the final braze weld is made

Fig. 9 After the weld cools, excess metal is removed. The weld area is cleaned and painted

and the hole was completedly filled up with bronze welding rod. The last step was to drill and tap the new hole so the sprocket could be put back to use again.

In the third job—a fairly common one—a bent tricycle frame was repaired. First the frame was cut apart at the bend and the ends hammered into shape. A piece of steel tubing, later removed was inserted into each end to back up the frame while it was being pounded back into shape. Then a tubular insert about 1½ in. long was hammered into one end and also forced into the other. This acted as a splint. The tubing and the metal on both sides of the break were cleaned thoroughly and then small tack-welds were made to hold the parts in proper position.

After the weld was made, excess metal was ground or filed away and the weld area thoroughly cleaned so that the frame could be repainted.

the AMERICAN WELDING SOCIETY

activities • related events

President Elect

FRED L. PLUMMER

Fred L. Plummer was born in 1900. He holds a Bachelor of Arts degree from Ohio University and a Bachelor of Science in Civil Engineering from Case School of Applied Science and a Master of Science degree from the same school. He is a Registered Engineer of the states of Ohio, New Jersey and New York. Mr. Plummer has written two books: one on *Statically Indeterminate Structures* and the other on *Soil Mechanics and Foundations*. He is author of more than thirty articles published in various technical journals of which two on Pressure Vessels were published in THE WELDING JOURNAL and *The Oil and Gas Journal*.

Mr. Plummer was an Instructor and Associate Professor at Case for 14 years from 1923 to 1937, teaching such subjects as Mathematics, Civil Engineering and Structural Engineering. He was a Lecturer during this period at Cleveland School of Architecture. He also lectured at John Huntington Polytechnic Institute.

In 1928, while on leave from Case, he was in charge of the structural analysis and design of the world's largest Airship Dock for Goodyear Zeppelin Corp. at Akron, Ohio, in association with Wilbur Watson & Associates, Consulting Engineers and Architects. He was also in charge of design of a seven million dollar steel bridge, being associated with Wilbur J. Watson and F. R. Walter.

During his stay with Case he was also consultant for a number of companies, such as the Truscon Steel Co., Republic Steel Co., Dow Chemical Co., U. S. Engineers Corps and others. From 1937 to 1940 Mr. Plummer was Chief Design Engineer of the Main Avenue Bridge Projects, Cleveland, Ohio. The project included the main bridge structure about one mile long with complicated approach structures. In was necessary to partially wreck and remodel many buiklings, move and reconstruct many sewer and utility lines. The complete project cost about eight million dollars.

Since 1940 to date Mr. Plummer has been Chief Engineer and new Director of Engineering of the Hammond Iron Works, Warren, Pa. The company fabricates and constructs all types of shop- and field-erected steel plate structures and

vessels used by the chemical, rubber and petroleum industries.

He is also General Manager, Hammond Latino Americana Construction Co., operating outside continental United States. Mr. Plummer is also a member of the Bailey Bridge Mission to Japan. He was head of a group of engineers and production managers sent to Japan by the Corps of Engineers, U. S. Army, following the outbreak of the Korean War, to assist Japanese manufacturers and fabricators of steel in setting up procedures and facilities for producing necessary special steels and fabricating Bailey Bridge parts which would be interchangeable with those produced in United States and Great Britain. Mr. Plummer is a member of many engineering societies and scientific groups. In all of these he manages to take an active part as indicated by the following committee membership.

1. American Society of Mechanical Engineers: Subcommittee on Special Design of Boiler Code Committee; Petroleum Committee of Process Industries Division.
2. American Society of Civil Engineers: Committee on Design in Lightweight Structural Alloys.
3. American Society for Testing Materials: Committee D-18 on "Soils for Engineering Purposes;" Committee D-2, XV, "Measurement and Sampling."
4. American Petroleum Institute: Refining Division; Committees on Storage Tanks and Tank Welding.
5. American Concrete Institute: Committee 315 on "Detailing Continuous Beams and Frames."
6. AMERICAN WELDING SOCIETY: Director, 1941–44; President, Cleveland Section, 1938–41; Committee on Awards; Handbook Committee; District Vice-President, 1948–50; 2nd Vice-President, 1950–51; 1st Vice-President, 1951–52.
7. American Society for Engineering Education (SPEE): Council, 1935–38; National Chairman, Civil Engineering Division, 1936–37; Committee on Lamme Award, 1938–42.
8. Cleveland Engineering Society: President, 1937–38; Trustee, 1934–40; Elected Life Member, 1949.
9. Welding Research Council: Pressure Vessel Research Committee; Chairman, Fabrication Division, 1949–to date.
10. American Society for Metals: Chairman, Division of World Metallurgical Congress.
11. National Research Council.
12. Society of Sigma Xi: President, Case Chapter, 1934.
13. Tau Beta Pi: Council Member, 1932–36.
14. Phi Beta Kappa.

First Vice-President Elect

ERIC R. SEABLOOM

Eric R. Seabloom was born in Sweden and came to the United States in 1909. He attended the Lane Technical High School and the Illinois Institute of Technology. In 1917 he became associated with Crane Co., Chicago, Ill., as a draftsman in the Product Engineering Department, later serving as an estimator and designer. In 1921 he was transferred to the company's Engineering Laboratories as a testing engineer and did development work on industrial products. From 1925 to 1935 he served as Research Engineer in charge of the Industrial Section of the Laboratories.

During this latter period his interest in welding grew and in 1932 he was given the position of Welding Engineer in addition to his other duties. The rapid growth of welding necessitated relinquishing other assignments to devote full time to welding and welding research. In 1939 he was appointed Supervising Engineer of the Engineering Laboratories to coordinate the activities of the many laboratory groups. Since 1948 he has been Supervisor of Field Engineering. Welding still continues as his major interest.

Mr. Seabloom has been active in the AMERICAN WELDING SOCIETY for many

years, serving as a Director-at-Large 1943 to 1946, Vice-Chairman 1941–42, Chairman of the Chicago Section 1942–43, Director of the Section 1943–46 and 2nd Vice-President 1951–52. He is a member of the AWS Committee on Awards, AWS-ASTM Committee on Filler Metals, WRC Advisory Committee on Public Utilities Welding Research and has served on the Welding Handbook Committee, ASA Code for Pressure Piping, Technical Committee of the Pipe Fabrication Institute and other committees.

Mr. Seabloom has published many papers on welding and presented numerous talks, mostly on welding, before AWS local sections and other engineering groups.

His technical society affiliations, beside the AMERICAN WELDING SOCIETY, include American Society for Metals, American Petroleum Institute and Society for Non-Destructive Testing.

Second Vice-President Elect

J. H. HUMBERSTONE

J. H. Humberstone, Vice-President of Air Reduction Co., Inc., was born in Toledo, Ohio, Oct. 25, 1909. He graduated from Ohio State University with the degree of Bachelor of Metallurgical Engineering in 1931. After being associated with the General Electric Co. for several years as an Electrode Development Engineer, he transferred to the Arcrods Corp. at the time of its formation. Upon returning from his wartime assignment as a Research Supervisor of the War Metallurgy Committee, Mr. Humberstone became Director of Research and Welding Engineering for the Arcrods Corp. in which capacity he served until early in 1946 when he was appointed Vice-President in charge of operations. In 1948 Mr. Humberstone accepted a position with Air Reduction Co., Inc., as Manager of Apparatus Production and continued his association with the Arcrods Corp. as a Director, subsequently becoming President and later Chairman of the Board, which position he continues to hold.

When Air Reduction Co., Inc., embarked on a program of decentralization Jan. 1, 1950, Mr. Humberstone became President of the Airco Equipment Manufacturing Division and continued in that capacity until late in 1941 when he was elected to the office of Vice-President of the Corporation. Mr. Humberstone has been a member of the SOCIETY for many years, serving on various technical committees and holding such offices as District Vice-President and Director-at-Large. He is probably best known for his activities as a

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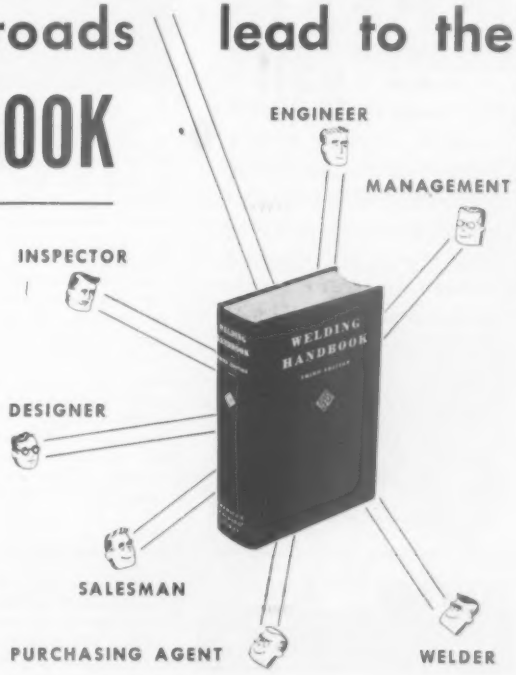

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member and Chairman of the AWS-ASTM Filler Metal Committee. He is the author of many technical papers on metal arc welding electrodes and holds several patents on coating formulas and production methods in that field.

Directors-at-Large

GAIRALD H. GARRETT

Gairald H. Garrett was born in Lawrence, Kan., on Mar. 17, 1894. He was graduated from Lawrence High School in 1913 and obtained his engineering education by night study.

He married Berenice Lemon on June 17, 1916, and has two daughters—Helen and Dorthe.

From 1913 to 1915 he was employed in the drafting room of the Lawrence Paper Manufacturing Co. He entered the engineering department of the Hardesty Manufacturing Co., Denver, Colo., in 1915, becoming chief engineer in 1920. In 1921 he entered the employ of the Thompson Pipe & Steel Co. as Chief Engineer, becoming vice-president in 1940.

He is a past chairman of the Colorado section of the AMERICAN WELDING SOCIETY. He was a director of the National Association of Manufacturers, 1946; president of the Colorado Society of Engineers, 1932; vice-president of the Colorado Engineering Council, 1946–47; president of the Colorado Engineering Council, 1947–48; and he has been active in technical committees of the American Water Works Association for the past twelve years.

MONRO B. LANIER

Mr. Lanier has been elected as a member at large of the Board of Directors of the AMERICAN WELDING SOCIETY. There follows biographical data taken from "Who's Who in America."

Lanier, Monro Banister, President, The Ingalls Shipbuilding Corp. since 1939; b. Huntsville, Ala., Dec. 9, 1886; University of Alabama, Class of 1907, Postgraduate Work, University of South, 1908; Sales Manager and Combustion Engineer, Monro-Warrior Coal & Coke Co., Birmingham, Ala., 1908–18; partner in same, 1918 to present date; Managing Director, Freeport Texas Co. and subsidiaries Freeport Sulphur Co. and Freeport Sulphur Transportation, 1930–33; Vice-President, Freeport Sulphur Co. and subsidiaries Freeport Sulphur Transportation Co. and Cuban-American Manganese Corp. and President of Cuban Mining Co., 1933–38; resigned from Freeport Sulphur Co., January 1938 to become Executive Vice-President of the Ingalls Iron Works Co.; President, the Ingalls Shipbuilding Corp., 1939 to present date. Was member of Shipbuilding Stabilization Committee of War Production Board; Shipbuilding Commission of War Labor Board; Advisory Board, Birmingham Engineering Procurement District; President, Gulf Shipbuilders Assn., 1942–48; Member, Board of Managers, American Bureau of Shipping, Director, Shipbuilders Council of America; Member, AMERICAN WELDING SOCIETY, Society of Naval Architects and Marine Engineers, Advisory Committee on Shipbuilding of National Production Authority, Brotherhood of Locomotive Firemen and Enginemen, Phi Delta Theta Fraternity. Clubs: Redstone and Mountain Brook (Birmingham), Whitehall (New York City), Boston Club and International House (New Orleans). Author: "Locomotive Feedwater Heating." Residence: 1128 S. 41st St., Birmingham, Ala.; Longfellow House, Pascagoula, Miss. Offices: 720 4th Ave., South, Birmingham, Ala.; 1 E. 42nd St., New York, N. Y.; and Shipyard, Pascagoula, Miss.

ISADORE MORRISON

Mr. Morrison has been elected a member at large of the Board of Directors of the AMERICAN WELDING SOCIETY to serve for a three-year term.

Isadore Morrison was born on May 13, 1905, in Buffalo, N. Y. He is the son of a sheet metal shop owner. He is now Vice-President of Morrison Steel Products, Inc., a firm which makes furnaces, steel garage doors, truck bodies, etc.

Mr. Morrison has been active in many community organizations. He has been interested in youth, and has worked for over 35 years in Boy Scout activities. He is an active leader in Buffalo's Community Chest Drive, the Buffalo Council of Social Agencies, the National Conference of Christians and Jews, and Buffalo's Jewish Center. He served as Buffalo's 1952 Chairman of Brotherhood Week, and is President of the Buffalo Bureau of Jewish Education, as well as a member of the Board of Governors of the Buffalo Jewish Federation. He is also on the Board of the State Commission against discrimination.

The SOCIETY activities of Mr. Morrison include past Chairmanship of the Niagara Frontier Section, Chairmanship of the National Membership Committee in 1952 and membership on the National Publicity Committee. He has been a member of the AWS for ten years.

HAROLD R. PRATT

Mr. Pratt has been elected to the Board of Directors for a three-year term.

Mr. Pratt is Principal Surveyor for the American Bureau of Shipping at Portland, Ore., and is a licensed Professional Engineer in the State of Oregon. He was born in Rutland, Vt., and graduated from the Webb Institute of Naval Architecture, New York, in 1932. In 1934 he received the degree of Master of Science in Mechanical Engineering from Harvard University. He was employed as a design draftsman by the Federal Shipbuilding and Dry Dock Co., Kearny, N. J., and the Sun Shipbuilding and Dry Dock Co., Chester, Pa., before joining the American Bureau of Shipping in 1938. Before the war he served at Boston, Mass., as a surveyor at the General Electric Co. Works at Lynn,

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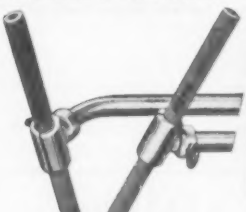

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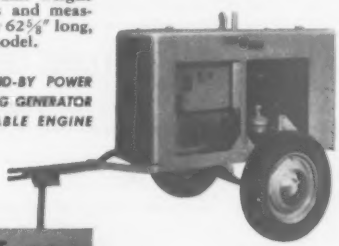

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Mass. During the war he was stationed at Portland, Me., and Panama City, Fla., working on the construction of welded merchant ships and in 1946 was sent to Antwerp, Belgium, to open an office there for the American Bureau of Shipping. While located in Antwerp, Mr. Pratt attended several meetings of the International Welding Organization in London and Amsterdam as an observer for the AMERICAN WELDING SOCIETY. He moved to Portland in 1949.

Vice-President—District No. 2

DONALD B. HOWARD

Donald B. Howard has been elected Vice-President of District No. 2 for a two-year term. He was born in Worcester, Mass., July 9, 1916. He is a graduate of Colgate University, class of 1939.

Mr. Howard was active in the Niagara Frontier Section through 1940. He became connected with the American Steel and Wire Co. in 1939. In 1947 he joined the American Car and Foundry Co. as a metallurgist and is currently Supervisor, Technical Services, in the General Laboratories of the Research and Development Department. Mr. Howard is a Charter member of the Susquehanna Valley Section, past secretary and present director of the Section. He is married and has one daughter, Gloria Ruth.

Vice-President—District No. 4

JOHN H. BLANKENBUEHLER

Mr. Blankenbuehler was born in Elizabeth, Pa. He graduated from Lehigh University with a degree of Electrical Engineer. Mr. Blankenbuehler then worked at the Westinghouse Electric Corp. in Pittsburgh for 23 years, starting as an engineer and was Manager of Welding Apparatus Engineering, in charge of all engineering on motor generator sets, transformer welders, automatic welding

equipment and welding accessories, at the time he left Westinghouse in 1946. Since then he has been working for Hobart Brothers Co. in Troy, Ohio, as Design Engineer.

While at Westinghouse he secured 30 patents on welding apparatus. Many of these patents are in production at Westinghouse now.

Mr. Blankenbuehler is a member of the Honorary Engineering Society Tau Beta Pi and the Honorary Military Society Scabbard and Blade. He is a member of the AMERICAN WELDING SOCIETY and has been Secretary and Chairman of the Dayton Section. He was a member of the *Welding Handbook* Committee of the AMERICAN WELDING SOCIETY for both the second and third issues. He has been a member of the C52 American Standards Association Joint Committee.

Mr. Blankenbuehler is a Fellow in the American Institute of Electrical Engineers and has been a Director of the Dayton Section. He is a member of the AIEE Committee on Air Transportation and the Committee on Electric Welding.

He is also a member of the American Ordnance Assn., the American Society for Metals, the Ohio Society of Professional Engineers and is a Registered Professional Engineer.

He is a member of the Rotary Club of Troy, Ohio, and received a certificate of commendation from the United States Navy for electrical design work done for the Navy during World War II.

Mr. Blankenbuehler has presented many papers before the various sections of the American Institute of Electrical Engineers and the AMERICAN WELDING SOCIETY. He also gave many talks on the subject of welding for other societies.

Vice-President—District No. 6

J. E. (ED) DATO

J. E. (ED) Dato was elected Vice-President, District No. 6, for a two-year term.

Mr. Dato was born in Fort Worth, Tex., May 3, 1915. He finished high school and attended postgraduate courses while working for the American Welding Co. at Fort Worth.

He joined the Linde Air Products Co. in Kansas City on Apr. 20, 1936, transferred to Wichita, Kan., in January 1937, spending time in the oil fields and prewar

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growth of the aircraft industry. After laboratory training, Mr. Dato was transferred to the Southwestern Region Office in Kansas City in June 1942, on process service activities with particular interest in the inert-gas welding processes. He is now Assistant Manager, Process Service in the Southwestern Region at Kansas City.

Mr. Dato is a member of AWS and ASM, having served four years as a director in AWS, Kansas City Section, as well as conducting talks to a number of the sections on oxy-acetylene and inert-gas welding processes.

Ships, Steam and Shapely Welderettes at the October Fall Meeting Events

A program of exceptional magnitude and of widespread interest has been prepared for the National Fall Meeting of AWS in Philadelphia, Oct 20th through 24th, at the Bellevue-Stratford Hotel. In addition to a comprehensive technical program, starting with the Adams Lecture at 10:00 A.M. Monday, the 20th, and carrying through to Friday, the 24th, there will be the formal and increasingly popular Presidents' Reception on Monday evening, an excellent Ladies Program during the week, interesting and highly educational plant visits and an outstanding banquet on Thursday evening.

On Wednesday morning, October 22nd, there are planned two plant tours of unusual merit. One is a tour of the Philadelphia Naval Shipyard or the Naval Air Material Center as preferred. The Shipyard tour will be highlighted by a trip through the Structural Shop, witnessing the fabrication of ship assemblies of steel and of aluminum, including a submarine undergoing major conversion. If time permits a tour of a battleship main deck will be allowed. A Shipyard brochure is now being prepared and may be available for distribution as a souvenir.

The Air Material Center tour will consist of a visit to the aviation Sheet Metal Shop observing forming, fitting and joining practices, the viewing of a catapault shooting a dead test load, demonstration of a pilotless helicopter, a trip through the Paint Shop; and demonstration of the ejection seat and a fire-fighting show.

The alternate major tour will be to the Steam Division of the Westinghouse Electric Corp. at Lester, Pa. Here the visitor will be brought into contact with the latest method and material used in producing steam turbine for central station power generation ranging up to 1100° F, 2250 lb pressure with capability up to 200,000 killowatts. He will also see a variety of heat exchanger equipment up to 130,000 sq ft surface condenser, feedwater heaters, hydrogen and oil coolers, as well as circulating pumps with capacity up to 150,000 gallons per minute. The latest fabrication techniques of low-alloy steels, submerged arc welding, low-frequency induction heating equipment for preheating and stress relieving weldments will be viewed, as well as various machines such as a 32-ft vertical boring mill, 160-in. lathe, 200-in. gear cutting machine, 1,000,000-v X-ray machine, 125-ton balancing machine and others.

Buses for all tours will leave the Bellevue-Stratford at 9:00 A.M. and be back at 12:30 P.M.

The following regulations apply to all tours. Visitors must be either U. S. citizens or, in the case of foreign visitors, have clearance from the Navy Department (through their attachés in Washington).* No cameras will be permitted to be taken into the plants or reservations. No notes may be taken nor sketches made. Visitors must submit their credentials at time they board bus, including a card giving name, address, company connection, position and citizenship status. No variations from the foregoing are permitted.

The Thursday evening, October 23rd, highlight is the Banquet or Annual Dinner in the Ballroom of the Bellevue-Stratford. At 6:30 a "pay-as-you-go" bar will be opened adjoining the ballroom for the convenience of those who wish to assemble prior to the dinner. (I'll meet you there!) At 7:15 P.M., *prompt*, the famous "Bellevue" Roast Beef dinner will be served in proper "Stratford" style. Harry W. Pierce, President 1951–52, will be the Master of Ceremonies and after brief introduction of the honored guests and the presentation of the Adams Lecture Award and Miller Medal, the entertainment will get under way. Two door prizes, one for a gentleman and one for a lady will be awarded; good remembrances of this gala 1952 event. For the next hour and a half the professional talent goes to work for your enjoyment.

* Copies of such clearance transmitted through regular Navy channels to the Philadelphia Naval Security Office.

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Definite table assignments will be made for everyone who purchases a ticket *in advance*. Effort will be made to locate individual ticket holders at tables with their friends or others from their section of the country. Reservations can be made *now* by contacting any member of the hard working Dinner Committee who have planned this fine event. Write: K. Wm. Ostrom, Chairman, c/o K. Wm. Ostrom & Co., 3717 Filbert St., Philadelphia 4, Pa., phone Ev 2-5444 or J. E. Norcross, Arcos Corp., 50th & Paschall Ave., Philadelphia, Pa., phone Sa 7-1500 or L. D. T. Berg, Arcway Equipment Co., 49th & Grays Ave., Philadelphia 43, Pa., phone Sa 7-3000. Tickets sold singly, by group or for complete tables.

Excerpt from June 12, 1952, Meeting Executive Committee

By-Law Ratification: The Assistant Secretary reported that wording for Article III, Section 3, "Nonpayment of Dues," was submitted to the membership at large on Apr. 25, 1952, for letter ballot approval, as follows: "Any member whose dues to the SOCIETY shall remain unpaid for a period of six months after they become due, shall be duly notified by the Secretary by letter *ballot* to the latest post office address as it appears on the records of the SOCIETY, stating that if such dues are not paid within a period of one month, he shall automatically cease to be a member of the SOCIETY."

This proposed wording was previously approved by the Constitution and By-Laws Committee and subsequently published in an issue of THE WELDING JOURNAL. It was observed by several members of the SOCIETY, and rightfully so, that the wording "letter ballot" was incorrect and the proper terminology should be "letter." This matter was referred to the SOCIETY's attorney and he communicated with the Assistant Secretary suggesting that the Executive Committee ratify the adoption of the proposed amendment with the word "ballot" deleted and that announcement to this effect be made in a future JOURNAL.

ACTION: Upon motion, duly seconded, the Executive Committee approved the attorney's suggestion that the word "ballot" be deleted and that announcement be published in a subsequent issue of THE WELDING JOURNAL.

34th National Metal Congress and Exposition, Philadelphia, Pa.—Oct. 18–24, 1952

More plant executives than ever before are expected at the 34th National Metal Congress and Exposition, Oct. 20–24 in Philadelphia.

William H. Eisenman, national secretary, American Society for Metals, Cleveland, and managing director of the event in Philadelphia, says a steady trend has been noted in recent years for officialdom and management to attend the annual metal show.

This year, exhibits depicting production, fabrication and application of metals will occupy 200,000 square feet, and will completely fill the four enormous display rooms of Philadelphia's huge convention structure. Practically every recent development to cut costs, increase production and improve the nation's metal output, Eisenman said, will be included.

Because of the exposition's scope and the interest of the technical sessions, he expects 50,000 plant managers, department heads, supervisory executives and metal engineers to register at the front door.

Technical sessions are programmed for all five days—Monday through Friday. Sessions will be held in Philadelphia hotels, where headquarters of four cooperating engineering societies will be established.

American Society for Metals will hold morning sessions in the Benjamin Franklin Hotel and afternoon sessions at Convention Hall; AMERICAN WELDING SOCIETY in the Bellevue-Stratford; Society for Non-Destructive Testing in Hotel Sylvania, and American Institute of Mining and Metallurgical Engineers (Institute of Metals Division) in Hotel Adelphia.

Centennial of Engineering Registration Procedure

A Centennial registration desk will be set up at the location of each principal society meeting. Desks will be placed conveniently near the registration facilities of the respective societies, but registration will be conducted by a separate staff of the Centennial Corp. There will be a registration fee of three dollars.

Each registrant will receive a Centennial badge and a master program covering all

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You get the most for your dollar when you buy General Electric stainless steel electrodes. Here are seven reasons why:

1. You get excellent handling characteristics in *all positions.*
2. You get good directional control because G-E stainless steel electrodes give you a very stable arc.
3. You get the minimum of spatter and can remove slag easily.
4. You can select the correct electrode for every application because G.E. offers industry a complete line of chrome and chrome-nickel types.
5. You can get G-E stainless steel lime-coated electrodes for reverse polarity DC and titania-coated rods for AC and reverse polarity DC.
6. You get the correct metallurgical deposit your specific job requires.
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He can help you select the best, most economical electrode for your specific stainless steel welding job.

Your G-E welding distributor also carries a complete line of other electrodes, accessories, AC, DC, Inert-Arc and Atomic Hydrogen welders. You can find his name by looking for General Electric under "Welding Equipment" in the classified pages of your telephone directory. *General Electric Co., Schenectady 5, N. Y.*

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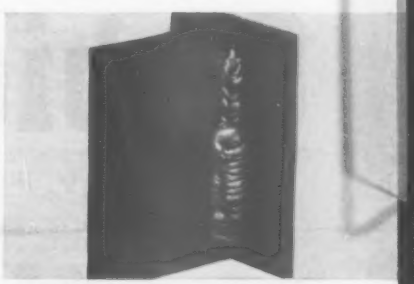

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GENERAL ELECTRIC

activities during the Convocation period, September 3rd to 13th. Registrants also may purchase tickets for the special functions scheduled by the corporation on Wednesday, September 10th—the Centennial Luncheon and the all-inclusive evening Centennial Party. The badge will permit attendance at the Convocation Symposia.

It is to be emphasized that anyone, whether or not a member of any society, is welcome to register and attend the various sessions.

Western Metal Congress and Exposition

The Eighth Western Metal Congress and Exposition sponsored by the American Society for Metals, in cooperation with western divisions of 20 national technical societies, is to be held in the Pan-Pacific Auditorium, Los Angeles, Calif., Mar. 23–27, 1953.

The Thirty-Fourth National Metal Congress and Exposition, to be held in Convention Hall, Philadelphia, Pa., Oct. 18–24, 1952, is sponsored by the American Society for Metals, in cooperation with three other national technical societies.

Mid-Southern District Meeting

On July 18th and 19th, under the leadership of District Vice-President A. E. Wisler of Houston, Tex., the Section Officers of Mid-Southern District No. 6 joined in a very successful meeting at the President Hotel, Kansas City, Mo.

The meeting officially opened on Friday evening with registration and a general hospitality section provided an opportunity for the Section Officers from Dallas, Denver, Houston, Kansas City, Oklahoma City, St. Louis, Tulsa and Wichita to renew acquaintanceship and to meet with the wives of many who had accompanied the officers to Kansas City.

The real business started out on Saturday at 8:30 A.M. with the welcoming address by District Vice-President Wisler and a review of his activities during the year, followed by each Section reporting individually on its activities with forecasts for the future. Ray Townsend, newly appointed Chairman of the National Membership Committee, outlined his plans for the coming year and was assured of the full support of his District No. 6 membership organization. At the luncheon, the Society's National Secretary, Joe Magrath, briefly reported on the activities of the National Society as planned for the future, as well as provided information on outstanding activities during the past year. During the afternoon, cross discussion was had among all officers present covering both National, District and Sectional activities. As a result of this discussion, many good suggestions were offered for problems that had been pestering the Sections during the past year.

The general business activities were followed by caucuses of the various Sections in the District for arranging their meeting programs for the coming year. At the close of the activities, a tour of the area of Kansas City, Mo., and Kansas City, Kan., was covered by sightseeing buses. Those taking the tour were shown the devastation that hit Kansas City, both residential and industry property-wise, devastation that cannot be illustrated in pictures, television or by word-of-mouth.

In the evening, the wives of the various attending Section delegates and the delegates joined in dinner at the Blue Hills Country Club in Kansas City, and then the entire group went to the Starlight Theatre in Kansas City for a very enjoyable evening's entertainment.

A great deal of value was gained from this District Meeting and a comparable activity is urged upon every one of the Society's Districts. For a number of years past, District No. 6 has been holding these meetings and they have been increasing in popularity and attendance, as well as value to all Sections concerned.

As stated before, the activity was honored by the attendance of the wives of many of the delegates. Those delegates attending were: John Viglini, John J. Fox, G. M. Allen, H. Beeman, W. E.

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Not only "MILD" steel, but also high carbon steel; cast steel; high-speed steel; manganese steel; stainless and all alloy steels; structural steel; aircraft steel, etc., in addition to all other metals from "A" for Aluminum to "Z" for Zinc can be joined faster, better, and more economically with one of the more than 150 different "Eutectic Low Temperature Welding Alloys". (All arc, torch and furnace applications.)

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SAVES 40% ON LEAD-COATED STEEL-PLATE WELDING COSTS

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TIME SAVINGS PER 100 TANKS!

Airtack and weld complete...43.7%
Wire Brush welds.....18.6%
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"This reflects a savings of 43.85 hours (40%) per 100 tanks. The comparisons were made on production runs and the hours per 100 tanks shown are actual time study standards used for incentive purposes.

"I wish to thank you for the splendid cooperation which made this savings possible." —*L. L. D., Ind. Eng., Stolper Steel Products Corp.*

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This new manual of yours sounds like a very helpful book. Send me a FREE copy with the understanding that there will be no cost or obligation now or later.

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City..... State.....

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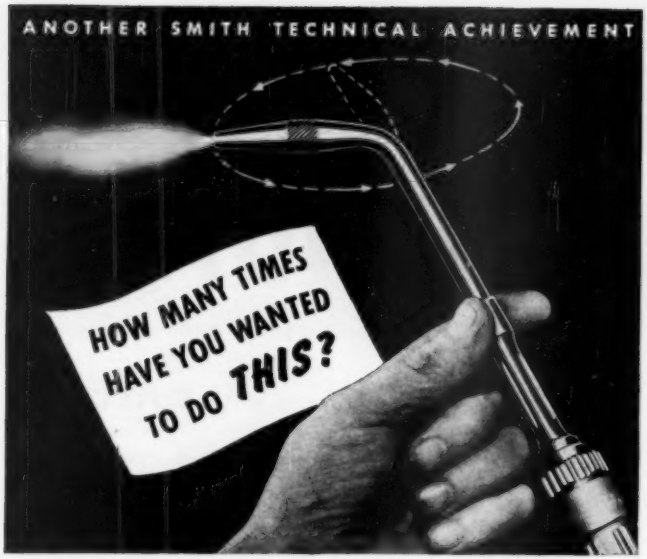
PORTLAND, OREGON • PITTSBURGH, PA. • HOUSTON, TEXAS • MILWAUKEE, WISC.



Rotate Tip in any direction *even while flame is burning!*

PLUS THESE EXTRA ADVANTAGES

CHANGE TIPS IN 6 SECONDS

No wrench needed. Fingers do the job. Just insert new tip—spin nut down—that's all.

GUARANTEED service for the rest of your life on all Smith's "LIFELONG" welding torch bodies and cutting assemblies.

THINK what this means in speeding up production schedules and reducing operator fatigue! The average welder is on a stop-and-go basis most of the day—shifting to new positions or stopping to adjust his work—and thus losing production time.

This new Smith Equipment makes it possible to work in the most comfortable and convenient position because the tip can be turned in any direction even while flame is burning. No time out to shut off flame, adjust tip angle or move your work. Just a twist of the finger, or a tap on the side of the tip does the job. It's a time-saver to help you increase production per man-hour and meet production schedules.

NOTE: This feature plus high speed change of tips (in 6 seconds—no wrench needed) is available in the following Smith equipment: Smith's "LIFELONG," MIDLINE and AIRLINE Torches.

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Please send me more information on the time-saving and money-saving features of your new torch.

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Bush, Orval W. Daniels, Harry L. Moberly, Ray Townsend, Joe Townsend, L. F. Douglas, F. Davenport, Bill Jaggers, J. Tipton, Morris White, C. Brinton Swift, David C. Card, J. L. Fry, H. Jackson. H. B. Klodt, V. A. Schroer, E. D. Anderson, Dean Broderson, Ed Dato, George Demecs, A. G. Hedstrom, Jim Kirk, Joe Payne, Les Powers, Frank Singleton, L. N. Williams, E. M. Hotchkiss, B. H. Allen, H. H. Wehner, A. E. Wisler, District Vice President, and J. G. Magrath, National Secretary.

Employment Service Bulletin

Position Vacant

V-274. Metals Joining Engineer. Large independent research organization has opening for Metallurgical Engineer with interest in and knowledge of research methods in brazing, soldering and welding. Excellent opportunity to advance with a growing organization.

Metallurgical engineer with background in arc welding to conduct electrode development work. Electrode development experience desired. Opportunity for original work and advancement. Box V-276.

Services Available

A-629. Welding Metallurgist. Degree. Age 25. Employed in welding laboratory for past two years investigating welding problems pertaining to material development and process application. Principal experience with the electric arc processes and high-temperature alloys. Prefer eastern location but will go anywhere.

Hardfacing Distributors Wanted

Expanding line of hardfacing rods and manganese steel weldments, including dipper tooth repointers, bar stock, plate, etc. National and local advertisers to back sales force. Extensive research facilities to keep ahead of the field. For further information, write Eox V-275.

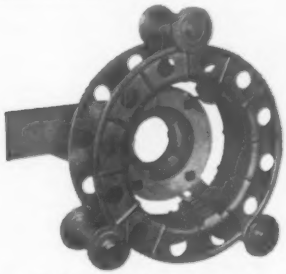
NOW

Double and Triple weight coils for automatic welding with the new REID-AVERY (free wheeling) REELS for Submerged Arc, Open Arc, and Gas Shielded Arc Welding

Raco Reel for 150-200# coils with floor mounting stand.

Decrease down-time by using larger coils. Machines now equipped for 25 lb. coils can use up to 75 lb. coils with these new reels.

These cast aluminum alloy reels ride on ball-bearing trunnions with deep flanges. The wire uncoils with remarkable ease and yet there is no chance of overrunning and throwing loops over the side. No brakes or drags of any kind are necessary. The wire itself prevents overrun. These "free wheeling" reels provide the absolute minimum load on the automatic welding machine.



Raco Reel for 25#-50#-75# coils. Mounted on popular submerged arc machine.

The Reid-Avery reels are available with stands for floor mounting or with special spiders for direct attachment to most popular automatic welding machines. Three reels 12" ID x 4" wide, 14" ID x 6" wide, and 25" ID x 4" wide nominal size are in stock for prompt delivery.

Raco Reel shown split for loading.

Note the simple split reel construction with suitcase type latches. Coils can be replaced in seconds and no wrenches or special tools are required.

We are equipped to supply all sizes of layer wound coils for these reels.

The REID-AVERY COMPANY

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NEW LITERATURE

Electrical Connection Catalog

Erico Products, Inc., 2070 E. 61st Place, Cleveland 3, Ohio, have just published their *1952 Electrical Connection* catalog. It is an elaborate booklet of 76 pages. Twenty pages are given to bus connections, including a complete description of the various types of welders for this purpose, together with complete welding instructions.

Tool and Die Salvage

A new, 64-page, profusely illustrated manual devoted to effective *Tool and Die Salvage Welding* procedures, is now being distributed without charge by Eutectic Welding Alloys Corp.

Copies of this new "How to Weld It" manual, *Tool and Die Salvage Welding*, may be obtained by writing directly to Eutectic Welding Alloys Corp., 172nd St. and Northern Blvd., Flushing 58, N. Y.

Hobart Arc Welding News

Volume IX, No. 2, *Hobart Arc Welding News*, a 16-page booklet of interesting photographs and articles on welding from all over North America, is now available. Copies are mailed free of charge to anyone interested in arc welding.

Many of the articles feature time and money saving applications. To get your copy, write the Hobart Brothers Co., Troy, Ohio.

Metallurgy for Engineers

Metallurgy for Engineers, Casting, Welding and Working, by John Wulff, Howard F. Taylor and Amos J. Shaler, is written to help the reader acquire "an adequate understanding of metals so that he may intelligently select and use them." The first half of the book explains the concept and principles that underlie metal processing from ingots to finished articles of commerce. The second half deals with the processes themselves. Throughout, the authors write from the engineering rather than the shop viewpoint.

Metallurgy for Engineers is based on material used by the authors for five years in teaching a course at The Massachusetts Institute of Technology. The experience of these five years is reflected in the careful arrangement of the book as it now stands. For example, at the end of each chapter the reader will find:

A summary of the most important points included in the chapter . . .

A list of definitions of the words, terms and concepts covered . . .

A group of questions which test the reader's understanding and indicate further the practical applications of the information in the chapter . . .

A list of references to easily available books which contain more information on some topic covered in the chapter.

This book consists of 624 pages and is published by John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y. The price is $6.75 per copy.

The Blacksmith's Craft

The Blacksmith's Craft which has just been puslished by the Rural Industries Bureau 35, Camp Road, Wimbledon, London, S.W. 19, to assist the training of apprentices at Technical Schools and Training Centers, and craftsmen in country workshops.

The basic techniques of blacksmithing are set out in 37 practical lessons, each lesson being presented as a sequence of photographs with explanatory captions. *The Blacksmith's Craft* is the only manual of its kind on smithing published today. Price, $2.00.

Automobile Body Reconditioning

Automobile Body Reconditioning is the title of a book by Theo. A. Wohlfeil, Erik E. Frisk and A. B. Saxman. The purpose of this book is to serve as a text, reference manual or handbook for teachers, persons in training and mechanics engaged in automobile body reconditioning, and those desiring to improve their knowledge by home study. Oxy-acetylene welding and sheet-metal straightening, both of which are extensively used in automobile body work, are presented in a way that teaches the student these skills correctly, and in the shortest possible time. The devices for teaching the fundamentals of automobile body sheet-metal and welding as pictured and described have proved to be especially helpful.

This book contains 157 pages and is published by the McGraw-Hill Book Co., 330 W. 42nd St., New York 18, N. Y. The price is $3.60 per copy.

New Southern Oxygen Co. Catalog

A new, 64-page catalog of welding and cutting equipment and supplies, safety equipment and electric hand tools has just been issued by Southern Oxygen Co. This new catalog illustrates and describes equipment used in the welding field today. Compiled for easy selection, the catalog shows a wide range of machines accessories, tools and parts needed for every type of welding and cutting job. In addition, a complete line of industrial safety equipment is illustrated. A copy of this catalog is available upon request to Southern Oxygen Co., P. O. Box 5087, Washington 19, D. C.

Oxy-acetylene Welding

Jefferson's Gas Welding Manual. By T. B. Jefferson. Published by Associated Business Counselors, P. O. Box 112, Skokie, 2, Ill., 1952. Paper, 5 by 7½ in., 112 pages. Price $2.00.

A new arrangement of material, concisely presented, is featured in this welding book. Written for the reader who knows how to weld, it is designed to fill in gaps in his knowledge of various metals and processes.

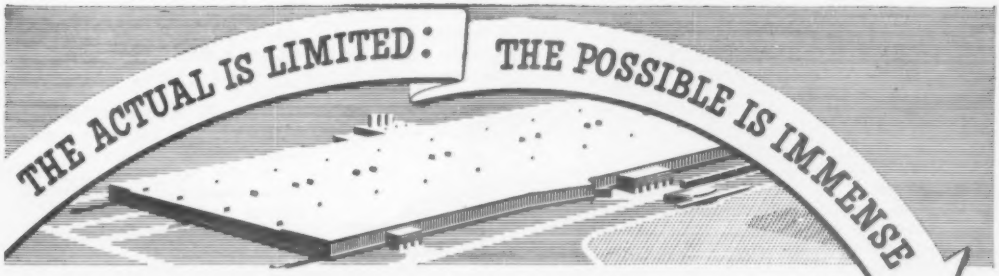
Beginners can learn how to do simple gas welding and flame cutting from the book, however, since operating instructions and explanations are carefully planned.

An unusually practical innovation in the book should be handy to both the inexperienced welder and the advanced student. Called "Jiffy Welding Guides," 20 separate sections present a brief round-up of basic facts for joining any metal that is weldable by the oxy-acetylene process. Welding fundamentals—some 50 gas weldable metals—are based on mild steel applications.

Common denominators for each of these "Jiffy Welding Guides" are the terms for steel welding. By translating them into temperatures and procedures for welding all other metals, brazing, braze welding and hard facing can be easily explained.

The flame cutting of various metals is covered in a similar series of guides. A third valuable part of the book is a chart that aids in the quick selection of the right process for joining dissimilar metals by gas welding. There is also included complete torch tip comparison charts for all makes of gas welding and cutting torches.

Additional useful tables, charts and clear illustrations throughout make this a complete and compact help for the welder and flame-cutting operator.



NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT

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WELDED DESIGN INCREASES RIGIDITY WITHOUT INCREASING COST

By **Eric Hartmann,** Experimental Research Engineer
The Porter Cable Machine Co., Syracuse, New York

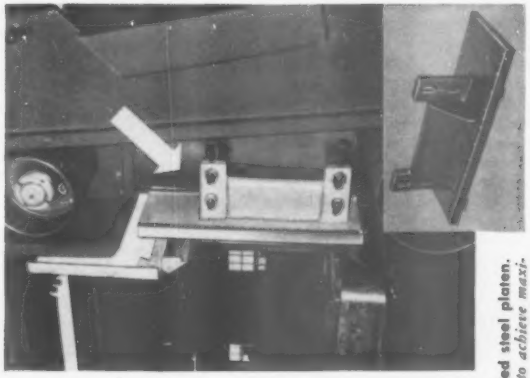

Fig. 3—Detail of Column on Porter Cable BG-8 Grinder. Shows assembly of belt platen support governing the ultimate accuracy and efficiency of the machine.

Inset: Rear view of welded steel platen. Shows efficient use of steel to achieve maximum strength and rigidity per pound of metal.

BY changing over the design of our belt platen support to welded steel construction, we have cut deflection over 90%. The former cast construction, (Fig. 1) would deflect from .017" to .020" under 400 pound table pressure. The present welded steel design deflects only .0015" to .002"... 10% of its original value.

Since steel is 2½ times more rigid than gray iron, it was possible to develop a more efficient product design on the platen itself without changing the basic dimensions of the machine or without increasing costs. On machine tools like ours, rigidity is basically important as it directly affects ultimate accuracy and efficient operation of the equipment.

WELDED DESIGN ALWAYS SAVES STEEL AND LOWERS COST

Fig. 1—Former Design—*Belt platen support for grinder was originally a casting. Required machining operations to finish the front face and the mounting arms.*

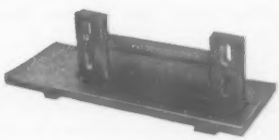

Fig. 2—Present Design in Welded Steel—*Is simpler to fabricate than the original construction. Components are pre-machined prior to welded assembly to simplify manufacture.*

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Machine Design Sheets free on request. Designers and Engineers write on your letterhead to Dept. 99.

THE LINCOLN ELECTRIC COMPANY
Cleveland 17, Ohio

THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPMENT

Book Review by Dr. G. E. Claussen

Die Schweisstechnik des Bauingenieurs (*Welding for Structural Engineers*) by Bernhard Sahling of the German Railways, Hamburg, and Kurt Latzin, Engineer in Dortmund, 278 pp., 343 illustrations, 6 x 8 in., Braunschweig, 1952, Fried. Vieweg & Sohn.

This is the second revised edition of a German welding text for structural engineers first published in 1937. It is a practical introduction to planning, designing, producing and testing welded joints in structural steel with special reference to official specifications.

The book deals first with weldable steels, the welding processes, shrinkage stresses and types of joints. Then follows a 54-page section on present methods of designing and producing plate girders, arches, prestressed concrete structures and tubular structures. A 40-page section on designing in accordance with the official specifications includes many numerical examples and completes the most valuable part of the book. The German Railway Specification DV 848 for welded plate girder railway bridges is explained in detail.

Subsequent chapters briefly discuss fabricating shop methods, welding in reinforced concrete construction, oxygen cutting, magnaflux and radiography. The last chapter describes important welded bridges and buildings in foreign countries, including Three Connecticut state highway bridges.

A New High-Yield Strength Alloy Steel for Welded Structures

The Welding Research Council, 29 W. 39th St., New York 18, N. Y., has published Bull. 13 on *A New High-Yield Strength Alloy Steel for Welded Structures* by L. C. Bibber, J. M. Hodge, R. C. Altman and W. D. Doty. This bulletin concerns a new kind of steel, its development, its metallurgical characteristics, its welding and gas-cutting characteristics, its low-temperature toughness, its applications and its engineering potentialities. This steel was developed by the United States Steel Co. to offer to industry a plate steel having a unique combination of properties, such as a far higher strength than has hitherto been available, superior toughness and good weldability.

As will be evident from the test results which will be described in detail, these rather formidable goals have been achieved This new USS "Carilloy" steel has been designated "T-1." It is characterized by yield-strength levels of 100,000 psi and above. At these high strengths it retains its toughness to much lower temperatures than ordinary structural steels. In addition, welds which develop the full strength of the base metal can be made in T-1 steel without preheating or postheating. This bulletin sells for $1.00 per copy and may be obtained through the American Welding Society 33 W. 39th St., New York 18, N. Y.

McKay Technical Report Covers Welding Electrodes

The McKay Co. technical bulletin covering Frogalloy Electrodes describes the operation and usability of Frogalloy M and Frogalloy C Electrodes. These two electrodes were especially designed for applications which require weld metal that will withstand wear under impact with minimum deformation and without spalling or cracking.

Typical uses for Frogalloy Electrodes include the build-up and repair of high-manganese and high-carbon switch points, frogs and crossings; maintenance welding of wobblers, spindles and other rolling mill equipment; the welding of high-carbon heat-treatable castings, machined carbon steel assemblies and high-carbon, high-manganese steel plates. They also are suitable for building up worn power-shovel teeth, road scrapers and other earth-moving equipment subject to excessive abrasive action.

A chart detailing Hardness versus Impact of both Frogalloy M and Frogalloy C Electrodes is part of the report.

For your copy of this useful data, write the McKay Co., 303 McKay Bldg., Pittsburgh 22, Pa., and request Tech. Bull. No. 8.

New Welding Magazines

Two new foreign welding magazines made their first appearance this year. A magazine called *Varilna Tehnika* is published in the city of Ljubljana in Slovenia (Yugoslavia). The editorial staff comprises Dr. Dusan Avsec, Dr. Milds Marincek, Prof. Dobromil Uran and Pavel Stular. Their address is Miklosiceva cesta 16, Ljubljana. The first issue contains the following articles:

1. "The Advantages of Back-to-Back Angles for Welded Construction," by M. Marincek. The Steel Construction Institute of the local technical college has developed methods of welding standard angles back to back to form larger structural sections. Buckling tests show that the back-to-back arrangement is superior to face-to-face.

2. "Welding Rods and Electrodes," by Leo Knez. A general discussion of gas welding rods and covered electrodes is followed by a description of domestic production of rods and electrodes at the steel plant in Jesenice and the electrode plant in Zagreb.

3. Practical instructions on fluxes and techniques for welding magnesium and aluminum.

4. Reviews of Russian articles on expanded tips for gas welding and on multiple electrode welding.

The other new welding magazine is called *Citogéne* and is printed in Milan, Italy (3, Piazza Franco Martelli). The editorial in the first issue by Georges Malamoud, president of the Centre de Développement de la Holding Intercito, states that the magazine will promote Oerlikon electrodes. Five firms cooperate in publishing the magazine, namely: Elektrodenfabrik Oerlikon in Zurich, Switzerland; S. A. Soudometal in Brussels; Forges et acieries de Commercy, France; S. A. Guiral Industrias Electrkas of Zaragoza, Spain; and Societa Siderotermica in Milan, Italy.

The first issue contains the following articles.

1. "Deep-Penetration Welding," by R. J. Mouton, Director of the Research Committee of Holding Intercito. Deep-penetration electrodes, developed by Belgian Soudometal several years ago, produce full penetration fillets and butts in the horizontal position in plates up to 0.67 in. thick. The fully penetrated welds have excellent fatigue strength.

2. "The Citoflex Electrode and Its Applications," by M. Parmeggiani, of Siderotermica. These are cellulose covered electrodes patterned after American 6010 particularly for welding pipe lines.

3. "Installing High Pressure Steam Piping," by R. Orophane (Commercy). Installations for 1300 psi and 975° F use 2% Cr, 0.5% Mo steel or 2¼% Cr. 1% Mo steel. Electrodes with a basic covering are used. Grooved backing rings are used. Induction preheat is 440–530° F, postheat is 1250° F.

4. "Effect of Current on Arc Welding," by M. Q. Aragones. Mechanical properties of welds made with different currents are compared.

Ampco News

The second quarter *Ampco Welding News* has just been released by Ampco Metal, Inc., Milwaukee, Wis.

Completely illustrated case histories give detailed information on prewelding preparations, welding processes and techniques. Among the articles is the fabrication of floating tube sheets used in acetic acid service welded with the inert-gas consumable electrode process.

Other features include the correct selection of resistance welding tips, "Ampco-Facing" cast-iron gears, die cutter drive shafts, bag machine-drum finger cams, soft steel sprockets, etc.

For your free copy write Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

Remember the trade marks "tt" and "TUBE-TURN" are applicable only to products of TUBE TURNS, INC.

Engineered to save maintenance manhours

Scrappy says, "Aid defense—more scrap today... more steel tomorrow."

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THIS TUBE-TURN WELDING ELBOW is engineered for shape, size, dimension, and wall thickness . . . to provide you with permanent, leakproof piping. It is forged by the only process that produces a wall as uniform in thickness and true in circularity as the original seamless pipe . . . guaranteeing accurate fit-up and *full strength throughout.*

More than ever, any piping installation you make should be maintenance-free, and have extra long life . . . that's why it pays to *specify* TUBE-TURN Welding Fittings and Flanges. For good service call on your nearby TUBE TURNS' Distributor . . . you'll find one in every principal city.

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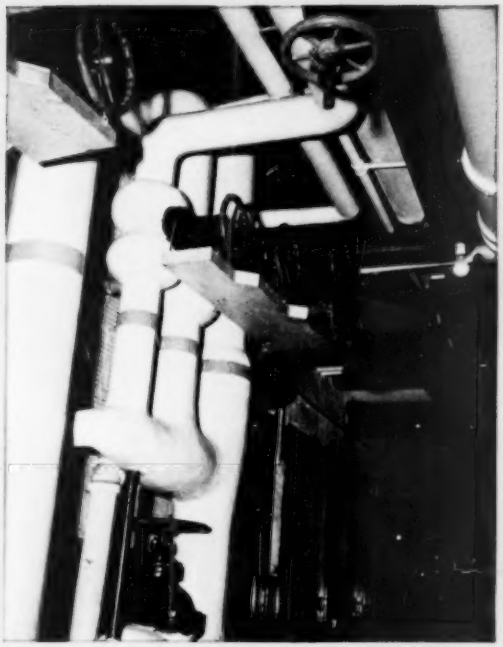
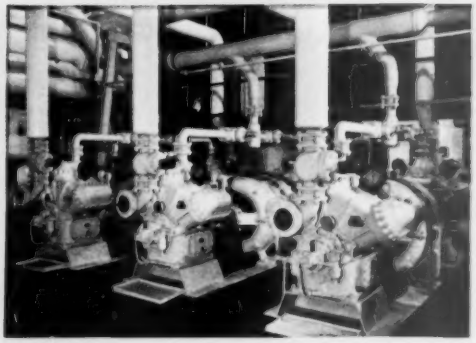
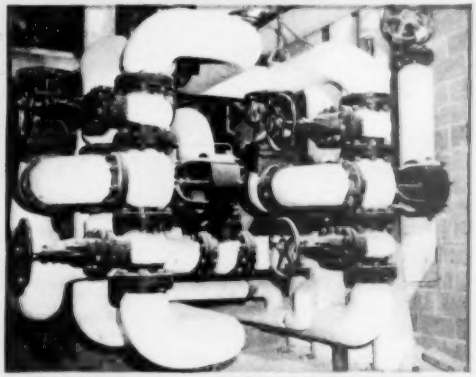
Large buildings cut maintenance with welded piping ...using TUBE-TURN Welding Fittings



FAMOUS HOTEL—New York's Waldorf Astoria uses 160,000,000 pounds of steam annually . . . and has the most extensive air conditioning system in the world. For top efficiency, all main lines, such as this piping to a steam header, are welded. Directional changes are made with TUBE-TURN Welding Fittings. All necessary types of welding fittings for any job, large or small, can be obtained from TUBE TURNS, INC. . . . which offers the world's broadest line of welding fittings and flanges, in a wide range of types, sizes, and more than 40 different alloys.



DEPARTMENT STORE—Long known for progressiveness in the retail field, the Lazarus Company was one of the first to air condition its selling areas. Facilities have since been extended to all 32 acres of floor space. To keep maintenance to a minimum, an all-welded piping system, using reliable TUBE-TURN Welding Fittings and Flanges, was specified for refrigeration equipment, condensers, pumps, etc. Thus joints are permanently leakproof, and insulation is on for life.



HOSPITAL—All piping from 2" up, for new addition to Mount Carmel Hospital in Columbus, Ohio, is welded, with TUBE-TURN Welding Fittings specified throughout. In this maze of steam piping to a hot water converter, welded piping fits neatly into a small space. With no flanges to work around, insulation was applied easily. This leakproof piping system eliminates the danger of interruption of vital services.

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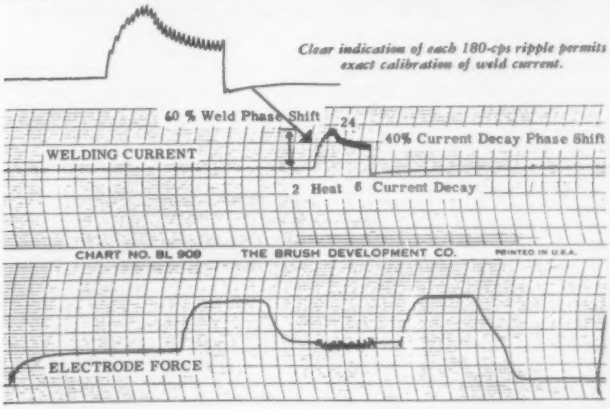
LOUISVILLE 1, KENTUCKY

New Brush Welding Analyzer

Brush Analyzer (BL-213), used here on Sciaky 3-phase resistance welder, consists of Universal Amplifier, modified D-C Amplifier, and special Direct Writing Oscillograph. Resistance-sensitive force pickup is mounted on electrode, toroidal coil, current pickup on lower horn.


Clear indication of each 180-cps ripple permits exact calibration of weld current.
60 % Weld Phase Shift
24
40% Current Decay Phase Shift
WELDING CURRENT
2 Heat 6 Current Decay
CHART NO. BL 900
THE BRUSH DEVELOPMENT CO.
PRINTED IN U.S.A.
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Dual chart of welding current and electrode force. Timing, and other variables are easily determined. Chart is recorded instantaneously . . . saving time.

Gives you written proof you meet specifications

The new Brush Welding Analyzer helps you meet specifications without trial and error, and saves time in troubleshooting on three-phase resistance welders, single-phase resistance spot, projection, and seam welding machines.

Chart records, which are immediately available, show the magnitude and timing of variables, and give written proof of the calibration and consistency of operation of equipment. The dual chart records welding current and electrode force . . . showing contact gage settings, precompression force, weld force, rate of rise, forge force, and time of operation in milliseconds. Faulty firing of ignitron tubes or other difficulties are clearly indicated on the chart.

Investigate time-saving Brush Analyzers for welding analysis, and for studies of A-C or D-C voltages or currents, strains, displacements, light intensities, temperatures, and other static or dynamic conditions. Brush representatives are located throughout the U. S. In Canada: A. C. Wickman Ltd., Toronto.

For complete information write The Brush Development Co., Dept. JJ-36, 3405 Perkins Ave., Cleveland 14, Ohio.

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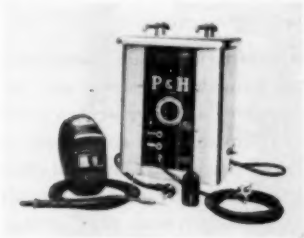
NEW PRODUCTS

Small Shop Welder on Market

Harnischfeger Corp., Milwaukee, introduces a new limited type input welder around the theme, "Save time and money by doing your own welding." This new model with a high open circuit voltage of 65 v, boasts a welding range of 20 to 180 amp, making it ideal for welding thin fender metal on up to repair welding of such heavy steel as tractor hitches.



P & H engineers say this new model is the only limited input type welder with "Dial-Lectric" Control. Just a three-quarter turn of this "Dial-Lectric" knob provides continuous heat control from minimum to maximum capacity. Machine has both High Range, for general purpose welding, and Low Range, for light gage welding. Tests show this P & H Welder uses about 1 kwhr of electricity per hour of operation.

Welder comes fully equipped with all accessories, including cords, cables, welding helmet with protective lens, P & H welding electrodes and an illustrated welding manual. For full information on the P & H Model TR-181 Welder, write for Bull. W-71-3, Harnischfeger Corp., 4400 W. National Ave., Milwaukee 14, Wis.

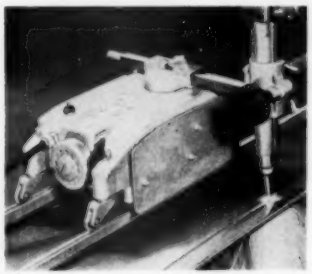
Detects Minute Gas Leaks

Leak-Tec is a new scientific development, specifically designed for detection of leaks. It spreads over cracks and crevices and creates a growing cluster of live bubbles wherever a leak occurs. It quickly detects all gas leaks—even minute leaks that will not show up by the flame test or other ordinary means. Leak-Tec is furnished in flexible, plastic bottles. These are light in weight, of hand size and easy to carry. They are far superior to the old soap-and-water method that frequently left small leaks undetected. Leak-Tec is a product of Cargille Scientific, Inc., 117 Liberty St., New York 6, N. Y.

Portable Machine Carriage

A low-cost, lightweight machine carriage for straight-line, bevel- and circle-cutting of metals—plus many types of welding and flame-treating jobs—has been developed by Linde Air Products Co., a Division of Union Carbide and Carbon Corp.

This machine, the Oxweld CM-45, is designed to do many jobs in the small metal-working shop, and to supplement heavier equipment in larger plants shipyards and mills. It weighs only 33 1/4 lb complete with blowpipe, so it can be moved easily from one job to another. The machine's compactness also makes it convenient for use in close quarters where larger machines cannot be used.



The CM-45 is housed in a sturdy, one-piece aluminum casting and is powered by a heavy-duty electrically reversible motor. A centrifugal type governor covers a stepless speed range of 4 to 32 inches per minute. Other speeds are possible if special motor gear heads are used. A simple gearing system and a mechanical clutch permit disengaging the gears for free-wheeling.

Operating controls consist of a three-position (on-off-reverse) motor switch, a speed-control dial that can be preset or instantly adjusted at any time during operation and a two-position clutch level. All controls are conveniently grouped together at the rear of the machine. Starting, stopping and reversing can be handled by a single control when the clutch is engaged.

The two forward wheels are drive wheels. These are knurled for better traction and tread hardened to give longer wear. The rear wheels are swivel casters that can be locked in position for straight-line work.

Bevels can be cut at practically any angle—top or bottom—either in straight lines or circles. The blowpipe can be set at the desired bevel angle by means of an adjusting pivot that has a calibrated indicator dial. Circles with diameters of from 2 to 54 in. can be cut quickly and accurately. Flame-treating jobs, such as low-temperature stress relieving, flame hardening, and flame softening, are done with suitable apparatus mounted on the CM-45.

The CM-45 can also be used to mechanize welding jobs, thereby producing more uniform welds with greater efficiency.

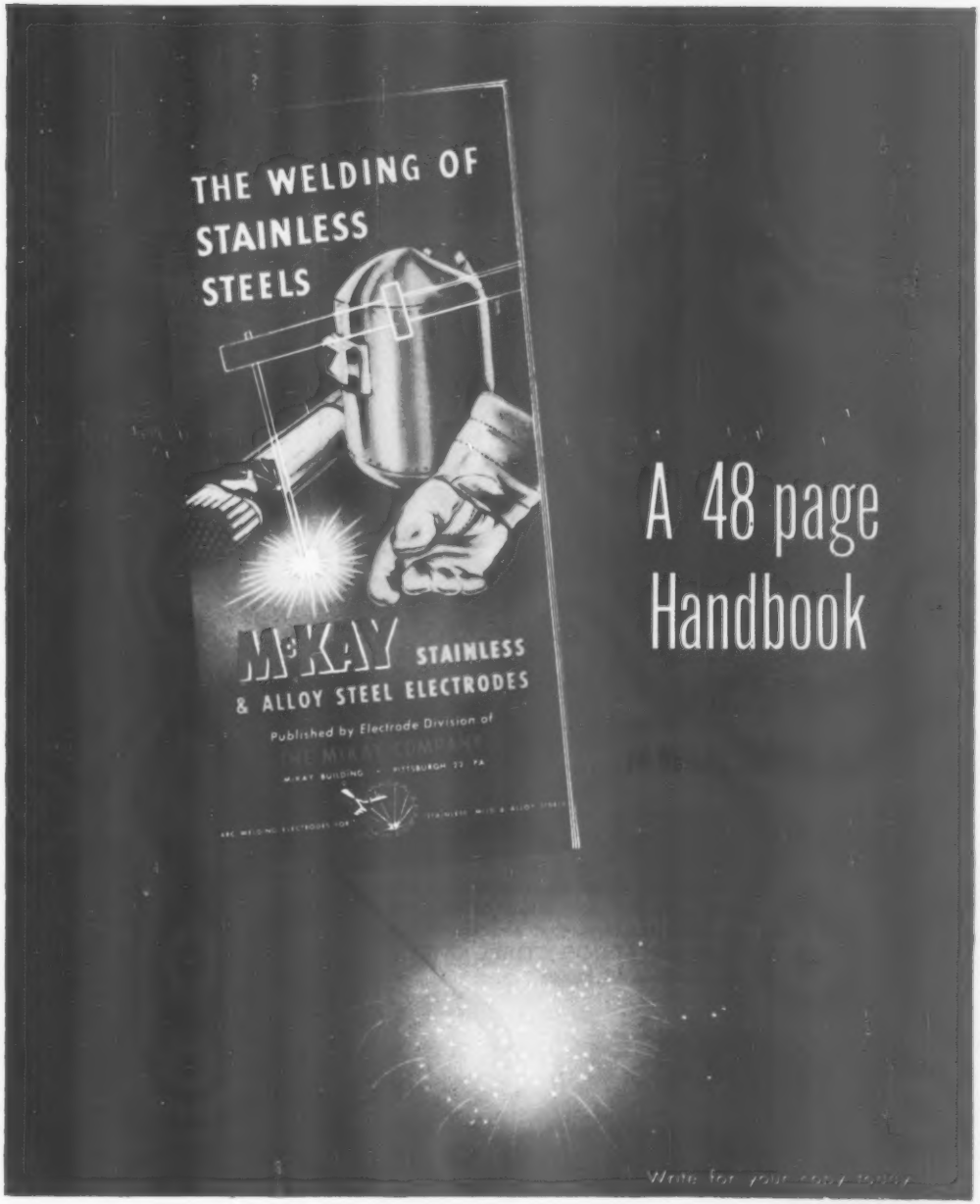
Torch-O-Matic

Savings in time, money and gas, and greater fire safety are reported for an automatic acetylene-air gas torch just announced by the Velocity Power Tool Co.

The pistol-shaped "Torch-O-Matic" lights at the squeeze of a trigger and shuts off upon release, eliminating separate operation and equipment for relighting, manual valve adjustment, pumping or priming, and warm-up. It is said to be especially well suited for intermittent or "on-again, off-again" work, such as in many plumbing, heating, piping, air conditioning, refrigeration and sheet metal jobs.

Squeezing the spring-loaded trigger simultaneously opens the torch gas valve and sparks the heavy-duty flint for ignition. Trigger also can be locked open for continuous flame. One-hand operation make for better user comfort and efficiency.

The Torch-O-Matic, only 12 oz in weight, provides instantaneous heat up to 2800 degrees. Combustion tubes available in three sizes—1/8, 3/16 and 1/4 in.—permit use of the torch for any air-acetylene job, from heavy soldering or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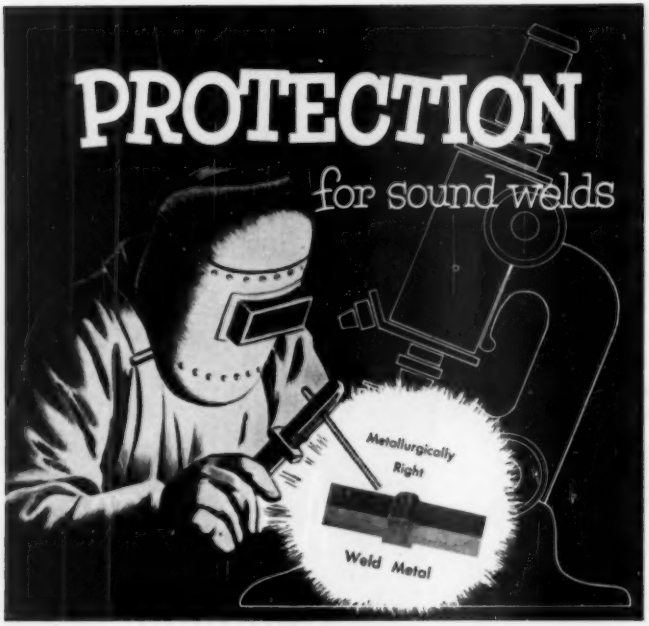

Use ARCOS "Quality Controlled" Stainless Electrodes

In the split-second flash of an arc, Arcos stainless electrodes produce the "right" weld metal for the job at hand. This is the result of Arcos' experience with fabricators' welding problems . . . competent research in the behavior of various grades of electrodes in use and weld metal in service . . . a strict application of quality control in manufacture.

The value of any electrode lies in the quality of the weld metal it produces. And that's where Arcos strives to build the values that count . . . soundness, specific mechanical or corrosion resistant properties, or microstructures that can stand-up to destructive service conditions. ARCOS CORPORATION, 1500 South 50th St., Philadelphia 43, Penna.

WELD WITH ARCOS

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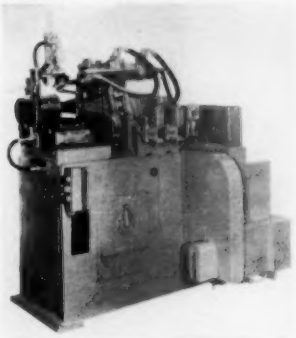
heating to the finest precision work. Accessories include pressure regulator, with either MC or B tank coupling; tank and operating pressure gages; hose and hose clamps; lighting flints; combustion tubes and nozzles, and extension tips.

Full details are available without obligation from the Velocity Power Tool Co., 7505 Thomas Blvd., Pittsburgh 8, Pa.

Joining Spouts to Stainless Coffee Pots

The welder shown in the accompanying illustration is manufactured by the Taylor-Winfield Corp. of Warren, Ohio, and is designed to spot weld spouts to stainless steel coffee pots. A special series spot welder equipped with one transformer for two welds, spot spacing, work indexing and electrode operation are all automatically controlled.

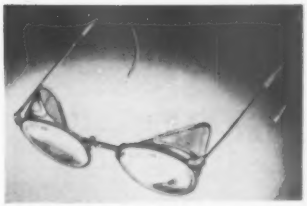


Two pouring spouts are welded to two pots during one operation of the welder. Two watertight seams of 66 spots each are made around the spout in 20 seconds. The external appearance of the 6-in. seam is so good that a minimum of polishing is required.

In operation, the operator loads two spouts in the lower dies under locator pins which provide location for two coffee pot bodies held down by a double clamp. When the operator pushes the "start" button, the electrodes automatically come down into welding position where successive welds are made at high speed with about a $^1/_4$-in. operating stroke.

At the end of the welding sequence, electrodes automatically retract and the indexing motor stops until the welder has been unloaded, reloaded and the "start" button pressed again.

The required loading and unloading time is so short that one operator can service three welders. On this basis, one operator and three welders can weld about 770 spouts an hour.



Safety Goggle

Pennsylvania Optical Co. introduces this newly designed industrial spectacle-type safety goggle, one of the "220 Series." Increased strength and lightweight are two of the features of the frame. Lenses are available in curved or flat standard 44- or 47-mm clear or absorptive safety glass.

Moisture Control Oven

The Grieve-Hendry Co., Inc., has announced an oven with sliding drawers for close moisture control of the various types of welding electrodes which are critically affected by such moisture.

This oven is portable and can be used on or close to the production line for storage and stabilization of stainless steel, low-hydrogen, tool steels and other electrode types which are susceptible to moisture pickup.

Weighing only 118 lb, the new oven is easy to move and can be stacked one on top of the other in groups or batteries. Temperature control is by thermostat and is adjustable to 325° F. Other models with temperature ranges up to 1000° F. are available.

The outside dimensions are 30 in. wide by 25 in. deep by 24 in. high. Inside dimensions—28½ in. wide by 24 in. deep by 20½ in. high. Each of the eight drawers is 2 in. high by 11½ in. wide by 23 in. deep, sufficient, to store electrodes of all sizes. Each drawer has a capacity of 50 lb of electrodes.

The unit plugs into a 110-v outlet, can be provided with outside reading thermometer, 60-min, 6- or 12-hr timer; red pilot light which shows when heating element is on; exhaust chamber for venting off fumes. It has fan-driven, forced-

Use ARCOS Low Hydrogen Electrodes

ARCOS GRADE	A.W.S. SPEC.
Tensilend 70	E7016
Tensilend 100	E10016
Tensilend 120	E12015
Manganend 1M	E9015
Manganend 2M	E100J5
Nickend 2	E8015
Chromend 1M	E8015
Chromend 2M	E9015

When you can deposit sound weld metal without changing electrodes to meet different welding positions—and use the same electrode on A-C or D-C current—you're saving time and inconvenience. With few exceptions, all types of Arcos Low Hydrogen Electrodes offer this advantage on a variety of base metals. That means a smaller inventory, since you can safely weld many jobs from start to finish with ONE ELECTRODE. Because Arcos Low Hydrogen Electrodes are "quality controlled," there's no danger of underbead cracking.

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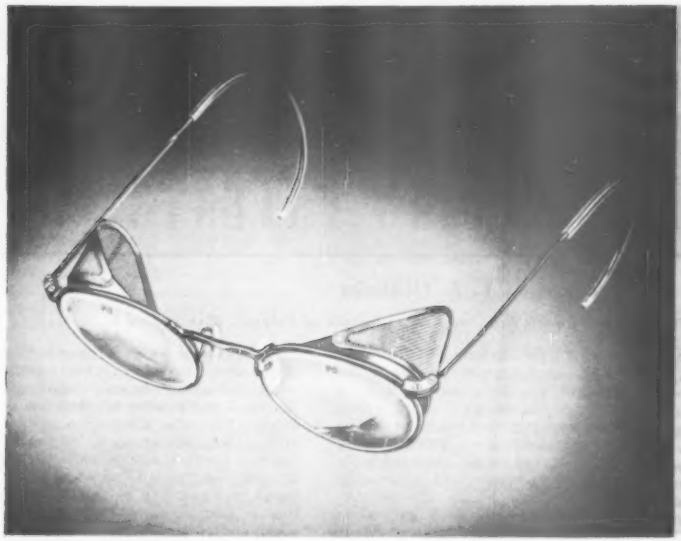

ANNOUNCES ITS NEW LINE OF SAFETY GOGGLES!

The 220 Series Goggles

The new 220 Series Goggles are designed to give the utmost in eye protection. Comfort is assured during continued wear by proper balance combined with lightness of weight. This results in worker approval and a higher factor of safety. Varied combinations make these goggles adaptable to many industrial operations requiring positive eye protection.

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air circulation which provides uniform temperature throughout. Grouped ovens may be operated at same temperatures or with certain oven cut out as required. High-temperature Inconel sheathed heating element provides efficient heating.

Full information may be had by writing manufacturer, Grieve-Hendry Co., Inc., 1101 N. Paulina St., Chicago 22, Ill.

Phosphor Bronze Electrode

Phosphor Bronze (Grade C—8% tin) weld metal of superior quality is deposited with the new Weldbest 620C electrode. This coated manual arc-welding electrode has excellent welding characteristics which provide ease of operation, handsome bead appearance and clean slag removal.

Mechanical properties of undiluted weld metal are Tensile strength, 61,000 psi; yield strength (0.2% offset), 33,000 psi; elongation in 2 in., 42.5%. X-ray qualities are very satisfactory.

Weldbest 620C Phosphor Bronze Electrode is manufactured by Weldwire Co., Inc., NW Corner Emerald and Hager Sts., Philadelphia 25, Pa.

abstracts of CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,601,383—Torch Cutting Apparatus for Surfacing Weld Metal—Harry S. George, Massapequa, N. Y.

George's patented torch relates to a surfacing machine for use in repairing battered rail joints. It covers the combination of an oxygen-cutting blowpipe, a carriage for the blowpipe, a main frame providing a guide for the carriage, and retractable frame supporting gage blades mounted on the main frame and having rail contact edges engageable with riding strips of the rails. These strips can be set in a common plane that coincides with the plane of the surface to be formed by the cutting action of the blowpipe. Other means are provided in the apparatus to aid in obtaining a cutting action along a path determined by the gage blades.

2,601,407—Device for Supporting Pipe Fittings for Welding—Lee W. Marshall, Terre Haute, Ind.

This patent is upon a special supporting device which includes a link bar that positions an arcuate bar member. Pipe gripping means are provided on the lower end of the arcuate bar member and special means connect the arcuate bar member to the link bar to support it.

2,601,893—Flame Gun—Fred W. Funke, Oakland, Calif.

This patent relates to a flame torch which has a discharge end with a generally frusto-conical mouth element, and means for providing a flame at its larger diameter open end. A nozzle is secured to the smaller diameter end of the element and has a through bore one end of which defines the discharge aperture and the other end of which defines the edges of an inlet aperture. The patented article has specific dimensional limitations for the apertures therein.

2,602,155—Welding System—Marcel Michelet, Paris, France, assignor to Welding Research, Inc., Chicago, Ill., a corporation of Illinois.

The patented welding system covers a control circuit that includes a welding transformer, electric discharge valves for passing current through the primary winding of a transformer and firing valves for controlling conductivity of the discharge valves. Grid biasing means are provided for the firing valves and include welding current control means for supplying an adjustable direct current voltage. Control transformers are connected in the circuit to superimpose an alternating-current voltage on the direct-current voltage and other means are provided for additionally superimposing a second direct current voltage which is a function of the voltage variations in the primary circuit and of impedance variations in the welding system.

2,602,412—Welding Rod Feeding Device for Torch Carriages—Carl H. Gerlach, Maple Heights, Ohio.

Gerlach's rod feeding mechanism includes a frame with a welding torch tip and a rod feeding attachment thereon. Wheels are provided and have outer rims for making contact with the working surface and a central shaft member. Means are provided so that when the rotatable wheels are rotated in a predetermined direction, the rod is fed toward the working surface. Such rod feeding means include a one-way drive mechanism so that the rod feed may be selectively controlled by a back-and-forth motion of the frame.

2,602,413—Aluminous Brazing Product and Method of Brazing—Mike A. Miller, New Kensington, Pa., assignor to Aluminum Company of America, Pittsburgh, Pa., a corporation of Pennsylvania.

A wrought aluminous brazing product is disclosed in the patent and it includes a plurality of aluminous structural members separated and joined by a layer of aluminous brazing alloy containing about 2 to 15% silicon. The alloy exhibits a liquidus temperature of at least 5° C below the solidus temperature of the structural members.

2,602,869—Welding Device—Cecil C. Peck, Euclid, and Willard Gunzelman, Gates Mills, Ohio, assignors to Cecil C. Peck Co., East Cleveland, Ohio, a corporation of Ohio.

This apparatus relates to the arc welding of two elongated metal members together in spaced local regions along their length. The apparatus includes supporting members for the metal members, a series of pivotal clamping fingers for clamping the members together, and means for moving the clamping fingers to clamping and released positions. An automatic welding head is mounted for horizontal traverse above and parallel to the work and additional means are provided to control the operation of the welding head.

2,602,870—Automatic Alternating Current Arc Welding System—Alfred F. Chouinard, Chicago, Ill., assignor to National Cylinder Gas Co., Chicago, Ill., a corporation of Delaware.

This welding system is one wherein a welding electrode is moved relative to work and an arc is maintained therebetween from a current source. An electric motor is provided for moving the electrode and the motor is connected to a fixed voltage source. Circuit means in series with the motor are connected across the arc, and the fixed voltage is substantially less than and opposed to the voltage applied to the motor. Relay means are provided responsive to the voltage across the arc and operative when such voltage is reduced to a predetermined value to connect the motor to the fixed voltage source in such a way as to retract the electrode and increase the arc voltage.

2,602,871—Nickel Welding—Robert A. Noland and Chester T. Szymko, Chicago, Ill., assignors to the United States of America as represented by the United States Atomic Energy Commission.

A process which comprises arc welding nickel and nickel-base alloys is disclosed in the patent. The process comprises using a shield gas mixture containing about 5 to 15% by volume of hydrogen and from 95 to 85% by volume of argon.

2,603,178—Brazing Machine—Martin T. Cahenzli, Jr., and Edward W. Mack, Chicago, Ill., assignors to The Harry Alter Co., Chicago, Ill., a corporation of Illinois.

A brazing machine which has a turntable, work holders on the turntable, drive means for causing rotation of the holders about their axes and means for rotating the turntable is shown in the patent. A source of brazing heat is located to act upon a workpiece carried by one of the holders at a certain position in the travel of the turntable.

2,603,475—Manually Operated Cutting Torch Machine—Vernon E. Rotsch, Whittier, Calif.

The cutting torch of the invention has a torch carriage including an elongate frame having spaced parallel rods thereon, and a carriage slidable longitudinally of the frame and including a torch holder. Supporting means are provided for the frame and include a certain work-engaging guide part carried by the frame with several guide parts being provided to engage work at an angle to the other guide parts.

2,603,735—Welding Process and Joint—Adolf G. Butler, Hawthorne, Calif., assignor to American Pipe and Construction Co., a corporation of Delaware.

Butler's method relates to joining a pair of single wires in end-to-end relation. It includes driving a sleeve on the end of each wire, placing the ends of the wires in abutting relation and passing an electric current therethrough to heat the wires and sleeves to fusion temperature. The wires and sleeves are forcibly pressed together axially to forge the joint and upset the ends of the wires and sleeves.

2,603,736—Carbon Arc-Torch—Henry William Snyder, Bozeman, Mont.

This patent is on an electrode holder for a carbon arc-torch or the like. The holder has a pair of electrical conductor tubes of insulating material positioned in parallel relationship by being secured at the ends thereof, and current carrying conductors extend into the tubes at the secured ends thereof. Electrical holding clamps are provided within the free ends of each tube for positioning electrodes that may extend angularly toward each other from the positioning tubes.

2,603,760—Automatically Controlled Alternating Current Arc Welding Apparatus—Hermann Kocher, Wettingen, Switzerland, assignor to Aktiengesellschaft Brown, Boveri&Cie, Baden, Switzerland, a joint-stock company.

This apparatus includes an electrode and a workpiece with a source of alternating current connected therebetween. A separately excited direct-current motor is provided for feeding the electrode toward and away from the workpiece, and a Ward Leonard generator is provided for energizing this motor. Special additional control means are provided including a rectifier so that a reversal of the electrode feed motor can be effected when the electrode contacts the work piece under certain operating conditions.

2,604,568—Electrode Holder—Herbert H. Peyreferry, Eddystone, Pa.

The patented electrode holder comprises an elongated barrel of conductive material with a central aperture therein. A resilient strap is positioned in the barrel aperture for contacting a welding rod extending into the barrel. A control knob engages the strap and extends through the barrel to aid in controlling the position of the strap.

2,604,569—Method and Means for Butt Welding—Francis S. Denneen, Cleveland, Ohio, assignor to The Ohio Crankshaft Co., Cleveland, Ohio, a corporation of Ohio.

Denneen's welding method comprises forming on one surface an outwardly tapering frusto-conical projection and on the other member an inwardly tapering frusto-conical recess with the angle of taper of the projection being slightly greater than the angle of taper of the recess so that the members when positioned in abutted relation are at least slightly spaced. High-frequency electric currents are induced to flow in the periphery of the surfaces of the abutted members, and low frequency electric currents are passed between the walls of the recess and the surfaces of the projection so that heat is generated at spaced portions of the surfaces simultaneously.

LIST OF NEW MEMBERS

Effective July 1, 1952

CHICAGO
Eilering, J. G. (C)
Kesselring, Frank (C)
Meyer, John G. (C)
Poloncsik, John (C)
Trecka, Andrew (C)
Williams, Henry Robert (B)

COLUMBUS
Elliott, Edwin G., Jr. (C)

DALLAS
Hudson, Les (C)
Paul, Jack G., Jr. (D)

DAYTON
Hickman, Samuel E. (B)

HARTFORD
Fahey, Thomas (C)
Shea, William B. (C)
Wiese, D. H. (B)
Wilsberg, Carl E. (C)

HOUSTON
Alhart, C. G. (C)
Cousins, Robert P. (B)
Purdum, S. C. (C)
Reichle, Donald S. (C)

INDIANA
Morgan, Warren E. (B)

IOWA
Barlon, John O. (B)
Waugen, John N. (C)

LEHIGH VALLEY
Dornblatt, Frederick S. (C)

LONG BEACH
Davidson, Durwood G. (B)
Frick, J. D. (C)
Garrick, Wilbert (B)
Knox, Albert James (C)
Phillips, Wendell Brooks, Jr. (D)

LOS ANGELES
Barnes, James T. (C)
Cameron, Hugh A. (C)
Cederlund, Stanley (B)
Foley, F. Wayne (B)
Garfield, Gerald (C)
Gross, William J. (C)
Killeen, Frank P. (B)
Lutz, Everett P. (C)
Maynard, Herbert (B)
Miller, L. C. (C)
Potter, Stewart H. (C)
Taylor, Elmer E. (C)
Templeton, John (C)

MARYLAND
Rudolph, William J. (B)

MILWAUKEE
Huna, Jack A. (B)

NEW JERSEY
Cannon, Joseph G. (C)

NEW YORK
Poetto, Peter G. (B)

NORTHERN NEW YORK
Schackleford, Woodrow W. (B)

NORTHWEST
Hertzel, William J. (B)

OKLAHOMA CITY
Blake, J. W. (C)

OLEAN-BRADFORD
Reed, Lineal D. (C)

PEORIA
Gould, Wayne (C)
Hague, Arthur J. (B)
Moore, A. W. (C)
Schlager, John W., Jr. (C)

PHILADELPHIA
Kuhn, William L., Jr. (B)
Schultz, George W. (B)

PITTSBURGH
Drigallo, William (B)
Lynds, John L. (B)
Ruschak, John D. (B)

ST. LOUIS
Adkins, Russel B. (B)

SAN FRANCISCO
Risoe, Hugo (C)
Smith, Robert A. (B)

SUSQUEHANNA VALLEY
Irons, James D. (B)

TOLEDO
Hlubik, Frank J. (C)
Walker, Bert J. (B)

TULSA
Hobbs, Richard David (B)

WESTERN MASSACHUSETTS
Belleveau, Archie W. (B)
Skukowski, Walter C. (B)

WESTERN MICHIGAN
Van Wieren, Ewald T. (B)

WORCESTER
Davis, Warren H., Jr. (B)

NOT IN SECTIONS
Bauvin, Rene E. C. (B)
Gray, Gifford George (C)
Jafet, Roberto (B)
Mackawa, Juichi (B)
McGeath, Glen (B)
Roland, Albert (B)
Zorn, E. (B)

Members Reclassified

During the month of July

BOSTON
Foley, Thomas F. (C to B)

DETROIT
Stephenson, Harry (C to B)

MILWAUKEE
Sommers, Victor (C to B)

NOT IN SECTIONS
Giraldi, Manlius S. (C to B)

NEWS OF THE INDUSTRY

Victor Equipment Co. Opens New Store

Victor Equipment Co. of San Francisco has announced that they have moved into their new store and warehouse, located at 145 Van Ness Ave., Fresno 1, Calif.

It is reported that a complete stock of welding and cutting equipment and supplies to meet the welders every need is available for immediate delivery.

New Railroad Welding Advisory Service

In order to give American railroads the benefit of specialized experience in the new uses of Eutectic Low Temperature Welding Alloys in their industry, a new Railroad Welding Advisory Service has been inaugurated by Eutectic Welding Alloys Corp., Flushing, N. Y. The new service is headed by Hugh H. Hurley, a leading authority on welding problems common to railroading.

Hugh H. Hurley

Welding Service

Miss Arlene Dahl, screen star Queen of the 1952 Indianapolis Speedway Races, smiles her approval in behalf of the entire racing fraternity on the Marquette Official Welding and Battery Charging Service.

It was Marquette's fifth consecutive year of being the "official" service. And for the fifth straight year Marquette equipment scored a perfect record. For the 1952 races, Marquette made over 1000 successful welds and performed battery charging service for all 53 qualifiers and starters.

Happy Travelers

Eight men recently traveled a combined total of approximately 50,000 miles from all corners of the world to spend a week in Cleveland studying the latest welding developments at The Lincoln Electric Co. Photographed here in front of a large layout plan of Lincoln's new $10,000,000 plant in which they met with company officials are (left to right): A. F. Davis, Lincoln Vice-President and Secretary; W. Cartlidge, Mexico City, Mexico; Y. Mori, Tokyo, Japan; W. Young, Cali, Columbia; F. Laurie, Calcutta, India; J. Reumont, Leopoldville, Belgian Congo; A. Noe, Casablanca, Morocco; F. Zevallos, Lima, Peru; W. R. Persons, Lincoln Vice-President, Sales; L. Tulby, Johannesburg, South Africa; R. Loynd, Lincoln Director of Training; G. Clipsham, Assistant to the President, Lincoln.

Armco International Corp., Middletown, Ohio, export agents for Lincoln, brought these men, their representatives, to this country for an intensive 8 weeks' training.

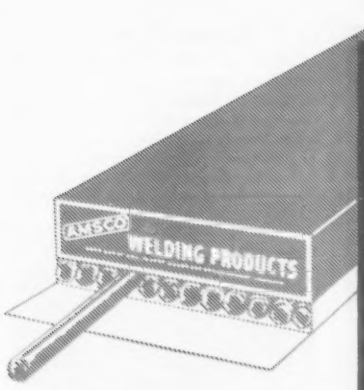
DryRod Oven Line Acquired by Phoenix Products Co.

On the occasion of its 60th anniversary, Phoenix Products Co., Milwaukee, announces purchase of a new welding line—the DryRod Electrode Oven—formerly sold by Philip Roden Co., also of Milwaukee. Although new to its list of products and services, DryRod, it was pointed out, is no stranger to the company's manufacturing and research departments. Phoenix engineers were active in the original design and development of this electrode oven, and have always handled the manufacture of DryRod for the Roden Co. It was only recently, however, that complete ownership of the product, including sales and merchandising rights, was acquired.

Designed to preserve mineral-coated (low-hydrogen type) electrodes from the damaging effects of normal shop moisture pickup. DryRod's thermostatically controlled electric oven employs circular design for uniform heat distribution.

Recent improvements to the DryRod Oven include a new protective thermostat control housing which makes the unit more rugged for heavy shop use. Also, where larger capacity storage is required, a new 900-lb model (handling rods to 24 in.) is now available, in addition to the standard 350-lb. capacity size.

For details on DryRod, write Phoenix Products Co., 4715 N. 27th St., Milwaukee 16, Wis.



How AMSCOATING with Amsco Hardfacing Rods saves you materials . . . manpower . . . money.

Amscoating these guide shoes kicks tube production up

AMSCOATING . . . stands for control of wear by Hardfacing . . .

Hardfacing Rods—and recommendations for their use—are as sound as the manufacturer who makes them. AMSCO has been fighting wear for a half-century—first with Manganese Steel, and later with AMSCO Hardfacing Products.

If you have a problem of wear caused by impact, abrasion, heat or corrosion . . .

Find out how AMSCOATING can save you materials . . . manpower . . . money!

Continuous production, greater safety and better weldability are three *good* reasons for Amscoating Piercer Guide Shoes.

These Piercer Guide Shoes are used at a large midwestern steel plant to hold a rotating hot bar in alignment during the initial piercing operation. Wear was not the main problem here. The condition to be avoided was "pick-up", where the bar becomes fused with shoe and literally explodes.

To lick this problem, which can result in expensive equipment damage and loss of life, the welding superintendent chose Amsco Thermalloy No. 4 for three reasons:

1. **Complete elimination of pick-ups . . . for greater safety and higher production**
2. **Better weldability . . . Thermalloy No. 4 covers heat checks, prevents small cracks that can cause pick-ups or seizing.**
3. **Amscoated shoes can be used many times . . . for big savings in replacement costs over a year's period.**

AMSCOATING permits big savings—through longer service and fewer replacements—on many other applications. If you have equipment that's subject to wear, the possible savings to you—are too big to be overlooked!

Write today for illustrated catalog—and nearest distributor's name.

AMSCOATING
THE RIGHT WAY TO SAY HARDFACING

Brake Shoe

AMERICAN MANGANESE STEEL DIVISION
399 EAST 14th STREET • CHICAGO HEIGHTS, ILL.

Other Plants: New Castle, Del., Denver, Oakland, Cal., Los Angeles, St. Louis. In Canada: Joliette Steel Division, Joliette, Que.
Amsco Welding Products distributed in Canada by Canadian Liquid Air Co., Ltd.

New WELDING IMPROVEMENT ASSURES

HI-CONDUCTIVITY
LO-CONDUCTIVITY

GREATER CONTROL OVER WELD POWER

WITH

Robotron
"CUSHIONED POWER"
WELDING TIMERS

THE PROBLEM: To help manufacturers meet more and more exacting specifications issued by government and civilian buyers in the welding of Aluminum, Stainless and Nickel-Alloy Steels, Coated or Plated Metals, or any combination of Dissimilar Metals regardless of conductivity.

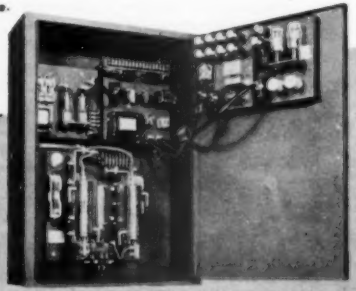
To design new, compact electronic controls that can be added to your old or new welding equipment with ease.

To increase welding production at lower cost.

Robotron's ANSWER: A new concept of Vernier Control, the Robotron "Cushioned-Power" Welding Timer pre-heats and prepares the welding material, welds and tempers according to specific needs, assuring welds of minimum surface indentation, maximum ductility and consistant uniformity.

- It welds all combinations of Hard-to-Weld, Plated or Dissimilar Metals.
- Reduces Weld Power KVA (heat) demand and usual required Electrode Pressures.
- Reduces Metal Spewing, Cracking and Surface Indentation.
- Reduces Electrode Pickup and Cleaning Time.
- Cushions impact on Welding Lines — Adds life to Electrodes.
- Can be Added to your present Welding Equipment.
- Can be used in Single-Phase Welding.
- Reduces overall Welding Costs.

Factory time-tested and proven like all other Robotron Electronic Control Equipment, this new "Cushioned-Power" Welding Timer features Compactness, Maximum Accessibility, Easy Installation, Easy Maintenance and Finger-Tip Modulated Power Control. Investigate how Robotron "Cushioned-Power" Welding Timers can increase YOUR welding production — No Obligation, of course.



MODEL WE30—H3C4
NEMA 7B Sequence — 1A Synchronous Timer with "Cushioned-Power" Control and 600 Ampere Ignitron Contactor.

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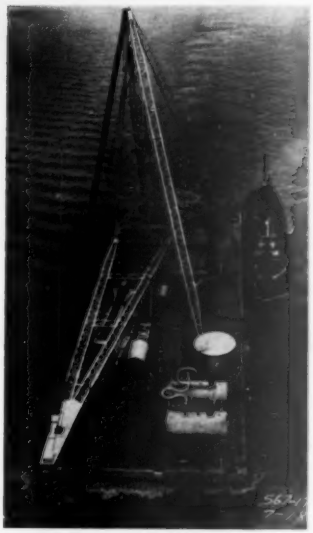
Marine Pile Driver

Some of the world's outstanding marine equipment has been built and outfitted by Avondale Marine Ways, Inc., and the most recent among these is the pile driver barge No. C-4, designed and built by Avondale for the Creole Petroleum Corp., and which is under tow to Venezuela by the M/T *Marion Moran* or the Moran Towing Co.



The barge, which has one square end and one rake end, is of all-welded steel construction and measures 210 ft in length by a width of 70 ft and a depth of 16 ft 6 inches. Built in accordance with the requirements of the American Bureau of Shipping the barge carries an ABS A-1 derrick barge classification. Hull plating is from 1/2 to 3/4 in. in thickness, with longitudinal framing supported by transverse trusses. A compartment, or well, measuring 14 x 18 x 8 ft deep, open at the deck end, will be used for the stowage of the weight intended for testing in pile driving operations. The barge is entirely steam powered by two Scotch Marine Dry-back type boilers with a working pressure of 175 pounds per square inch. Of particular interest is the boom, which is the largest built by American Hoist and Derrick and one of the largest in the world. Dimensions are 175 ft in length with a spread at base of 28 feet. The mast of the derrick is 120 ft high. The machinery platform supports a three-drum steam hoist to rated single line pull of 40,000 pounds. The derrick is swung by two steam engines geared to a 30-ft bull gear welded to the deck of the barge.

After all tests were completed, the boom, pile driver lead and other miscellaneous gear were securely lashed to the deck and otherwise protected for the sea voyage.

NEW! SIMPLIFIED! SMALLER!

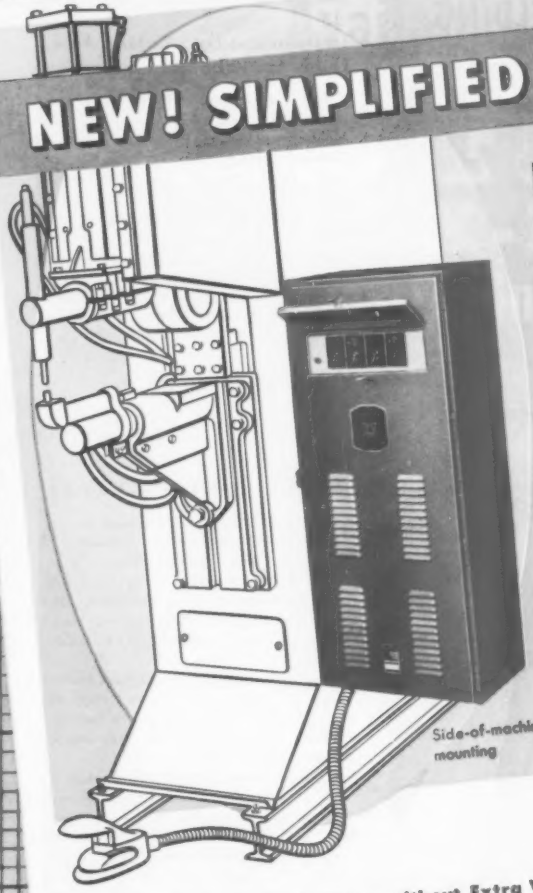
ELECTRONIC NON-SYNCHRONOUS WELDER CONTROL

Here is design simplification that affords significant advantages—easy installation, less maintenance, smaller size, mounting versatility.

Drastically simplified NEMA 3B weld and sequence timing circuit requires only 4 tubes plus valve relay and firing relay. Extreme consistency and timing accuracy are maintained. All tube circuits are "fail-safe." Firing of power tubes is synchronized to minimize transients and ease stress on welding transformer.

Interchangeable NEMA 3B and 5B timer panels are quickly detached from door. Plug-connectors to power pack in cabinet permit easy replacement.

Much smaller in size, this new controller (15" x 15" x 37") requires little more space than formerly needed for the ignitron contactor alone.



Side-of-machine mounting

Wall or catwalk mounting for gun welding applications

Wall or Machine Mounting without Extra Work

• Enclosure design permits wall or side-of-machine mounting with the same controller and without the additional trouble of relocating adjuster dial assembly. Installation is made easier by generous wiring space below contactor, and vertical wiring channel extending the full height of the cabinet. All components are arranged for maximum accessibility.

Write for Bulletin 8992 on Electronic Non-Synchronous Welder Control and its application to spot and projection welders. Address Square D Company, 4041 N. Richards Street, Milwaukee 12, Wisconsin.

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AC-DC Electrodes

GAS Welding Rods

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BURNING...
stable even at lower heats

SLAG...
clean, easily removed

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resists cracking down to very short stubs

SELECTION...
complete line for welding every type of stainless

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PAGE Welding Electrodes AND Rods

A steel plate breakwater was welded to the deck in the bow to protect machinery from seas and wave wash.

Independent Oxygen Mfg. Assn. Holds Annual Summer Meeting

The Independent Oxygen Manufacturers' Assn. held their Annual Summer Meeting at the Broadmoor Hotel, Colorado Springs, Colo., on June 23rd to 25th. One hundred and twenty-five people attended this meeting, representing oxygen companies in the United States, Canada, Mexico and the Hawaiian Islands. This was the largest attendance in the 10-year history of the association. Papers were given and open discussions were held covering subjects pertinent to the compressed gas industry.

California Vocational Training

Use of a carbon torch for hard facing, heating, bending and forging, and methods of soldering with a single carbon are some of arc welding's "modern tricks" that will be taught in vocational agriculture departments of numerous California high schools along with the regular techniques this fall.

It is the result of a special short course in farm welding given two groups of California high school agricultural instructors at California State Polytechnic college's annual "Skills Week."

"With electricity available on such a large percentage of California farms, arc welding has come into its own as an everyday tool in the farm shop," explains James F. Merson, head of Cal Poly's agricultural engineering department, who arranged the short course. "And modern equipment now makes possible many a job once too difficult or involved for the average farm welder."

Instruction was handled with the aid of portable booths and tables constructed by agricultural engineering students for the course.

Among other special projects presented during the course were safe welding practices, selection and care of arc-welding equipment, demonstration of butt-weld flat position, demonstration of vertical welds, identification and selection of electrodes, identification of metals, demonstration of cutting with arc and mild steel electrode, demonstration of welding sheet metal (16 and 18 gage), demonstration of Surfaceweld and single carbon techniques, demonstration of brazing, demonstration of hardfacing with each student completing a hard surface project on a plow share and hardfacing a ripper tooth or similar job.

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X-RAY UNITS
for Industrial Radiography

Only **FEDREX** gives you x-ray tube and all other high-tension parts combined in one single all-welded steel tank. All high-tension cables, cooling connections, separate transformers and cooling pumps have been eliminated. The end result of this advanced integral design is two small light-weight units, dustproof and waterproof, and with a remarkably high efficiency in operation.

FEDREX is quickly and easily set up. This feature, together with its small dimensions and lightness make it a truly portable unit.

CUTS COSTS - INCREASES OUTPUT

No more heavy maintenance and repair costs as with other units of traditional design.

One erection work FEDREX gives you 2 to 3 times the number of radiographs per working day than any other equipment.

Widely used in Europe, the FEDREX units are backed by 24 years of practical experience in the manufacture of X-ray equipment.

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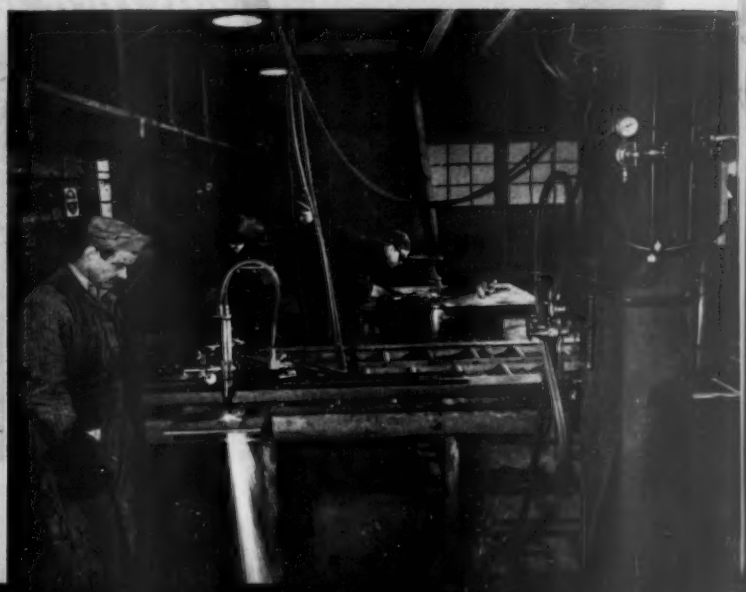
Above: Efficient, low-cost cutting of scrap is assured at the Bronx Iron and Metals Corp., New York, with use of Torchweld 75 Hand Cutting Torches and an up-to-date pipeline gas supply system. Piped from a trailer-serviced oxygen storage bank and an acetylene manifold, gases are conveniently at hand all over the yard from well-type stations, like the one seen in the picture. The steel well-cover closes when the station is not in use to permit normal traffic and yard use of the ground area.



At right: "We have reduced our gas consumption by 33⅓% and substantially cut our labor costs since standardizing on Torchweld equipment and installing an NCG manifold system," says Harvey Wallert, shop foreman; and Gene De Buck, maintenance superintendent, of Knoebel Iron Works, Inc., Chicago fabricators specializing in building steel. "The Torchweld No. 36 cutting torches we use really stand up in hard use. For instance, we use templates for hole piercing ¼-inch stock, and that puts a torch to a tough test. We also use NCG automatic flame cutting equipment, and Sureweld electrodes for electric arc welding."

Short-cuts to Lower Costs

NCG know-how boosts efficiency, increases output and lowers costs in plants of every kind and size throughout the country

Components for barges, towboats, derrick boats and other types of vessels are speedily cut from plate in the shops of the Hillman Barge and Construction Co.'s plant at Alicia, Pa. These two NCG RS Cutting Machines work directly from patterns made in the Hillman pattern loft to cut required shapes. Hillman, designers as well as fabricators, have used NCG products exclusively for the past 10 years.

One of the big answers to today's problem of holding down production costs is the use of more efficient tools . . . tools that will get the job done better and with less working time. If you *weld metals* with the electric arc . . . if you *weld them*, *braze them*, *cut them* or *treat them* with the oxy-acetylene flame . . . you'll find that NCG has the tool that will do it with top efficiency. Whether it's on a torch, a welding machine, an electrode or a cutting machine, you'll find—as so many others have—that the NCG trademark means you'll get the job done faster, with less effort, and with better results. And, *especially important now*, you'll find that NCG equipment lasts longer and requires less maintenance.

Representatives at 51 NCG offices and authorized NCG dealers from coast to coast can show you why it pays you to buy NCG products. Call the one nearest you now, or write us.

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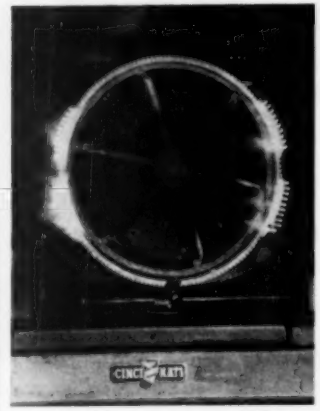
Starter Gears Get Hardening Treatment

Packard Motor Car starter gears get an efficient flame-hardening treatment that raises the hardness of the teeth from 350 up to 540 Brinnell hardness. The gears, 15 in. in diameter, with 159 teeth, are hardened in a Flamatic machine, made by Cincinnati Milling Machine Co.

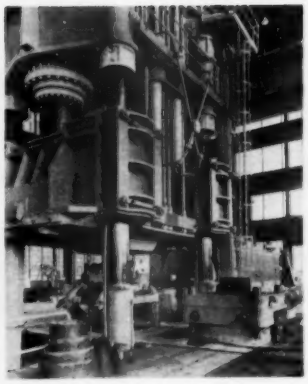


After a gear is put in the machine, oxy-acetylene flames are turned on. Ten flames from each of four Oxweld heating heads heat the gear as it spins around. In about 20 seconds, with hardening temperature at around 1500° F, the gear is dumped into an oil bath to be quenched. That is all there is to the operation, but there is more under the surface. The hardened gears will wear longer and perform more efficiently with the added hardness.

Nation's Largest Equipment to Make Steam for Power Shown by Babcock & Wilcox

The installation of the nation's largest press for forming boiler drum plate and the introduction into America of a method of forming heavy-wall hollow forgings by piercing and drawing an ingot were revealed by The Babcock & Wilcox Co. in an announcement made at its Boiler Division plant at Barberton, Ohio. Alfred Iddles, president of the company, speaking before a luncheon of news people during a demonstration of the equipment, said that it was an important part of the $30,000,000 expansion program which has been in progress by B & W since the close of World War II and is geared to meet the needs of the rapidly growing electrical industry for larger and more powerful boiler to produce more steam for power.

The new press and draw bench, built and installed by the company at its



Vertical press setup for ingot piercing, first step in forming a hollow forging

works here, will produce a rough hollow forging up to 35 in. outside diameter with 4 1/2-in. walls, in a matter of minutes. Until now it has been necessary to make such pieces of steel plate rolled and welded at the seam or from a solid forging with the center bored out. These forgings are used mainly for boiler parts and connecting steam lines operating at high temperature and pressure as is the trend today.

Forming Boiler Drum Plate

The vertical press has a normal capacity of 6500 tons or an intensified capacity of 8500 tons. It is equipped with massive bending beams 42 ft long and its open-ended design makes it possible to bend even longer plates. It is 64 ft over-all height from the bottom of the pit in which it stands. As a steam drum is composed of cylinders made from plate, the announcement said, a longer plate means that there will be fewer circumferential welds, with a subsequent saving in time and cost.

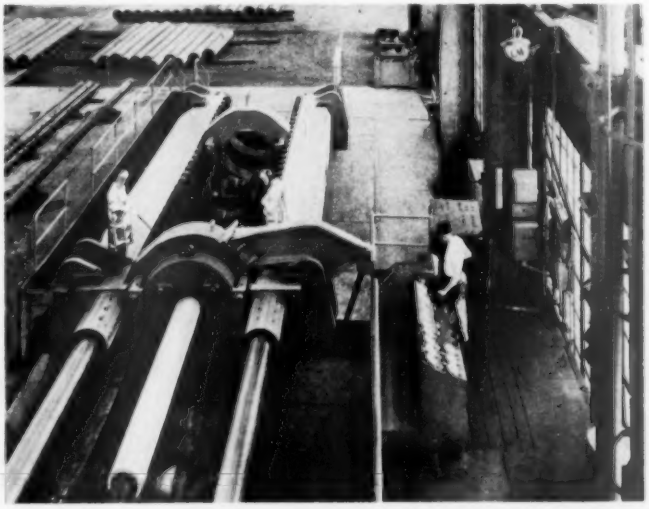
The four supporting columns for the press are giant steel pillars 52 ft high and 26 in. in diameter, each weighing 41 tons. The largest of the three press platens weighs 200 tons.

The press and draw bench were built of heavy welded steel plate, and are housed in a new shop building 105 by 275 ft and 92 ft high, designed especially for this extension of facilities on the plant site. A complete hydropneumatic pressure system to operate the equipment was installed at the Barberton plant. The seven water and air accumulators were designed, fabricated and installed by the Barberton works.

Blimp Blanket

Ryan Aeronautical Co., San Diego, Calif., exhaust heaters have gone to sea. To provide cabin comfort for blimp crews on antisubmarine patrol, the Navy's ZP2K airships are being equipped with Ryan heaters as they return to active service with Fleet Airship Squadrons. The backbone of the Navy's lighter-than-air arm, K-type blimps are an important member of the "hunter-killer" teams used to seek out and destroy enemy submarines.

Postwar submarine improvements, such as the snorkel breathing device, have



Drawing a hollow forging on the horizontal draw bench. The forging (foreground) is forced by the mandrel through a series of ring dies to produce a predetermined inside and outside diameter

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...tell working temperatures from 113° to 2000° F

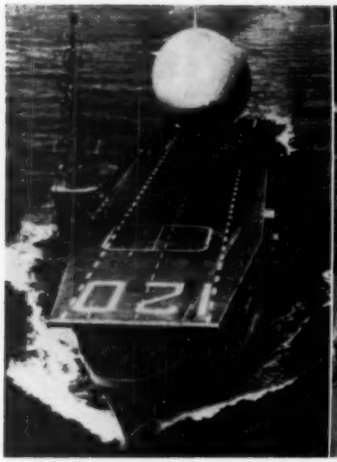


Fig. 1 Capable of flying around the clock, the Navy's Goodyear blimps joining Fleet Squadrons as an important member of antisubmarine patrol teams. The airships can land on carriers for fuel and provisions or refuel in flight from seagoing tankers

Fig. 2 Ryan exhaust heaters for Navy blimps are heat exchangers consisting of bundles of stainless steel tubes welded into concentric pattern. Heaters obtain heat energy from exhaust gases of blimp engines and warm air for cabin heating

Fig. 3 Typical Ryan exhaust system for Navy blimp showing the engine exhaust port take-off locations and the tailpipe for channeling the hot gases aft. Energy dispersed by this type of exhaust system is employed to warm the air necessary for blimp crew comfort. Such applications save the weight of added heaters and fuel—using exhaust energy otherwise wasted

made these undersea craft more difficult to detect. The Navy is meeting this challenge with a coordinated attack team consisting of surface vessels, planes and Goodyear blimps. In this trio, the blimp role is usually that of a "hunter" because of its ability to carry a great deal of electronic detection gear. Its unexcelled endurance and maneuverability make it a hovering "eye" of sharp perception. However, it can also become a deadly "killer" when occasion demands by bringing its machine guns, depth charges and other weapons to bear.

The Ryan heaters are actually lightweight heat exchangers which are attached to the blimp engines. Each heater is a circular cluster of eight stainless steel tubes contained in a cannular shroud. As the hot engine exhaust gases pass through the tubes, the air within the shroud is heated. This warmed air is channeled to the cabin through two floor vents, to maintain crew comfort on extended flights. The system saves the added weight of fuel and burners, ordinarily required, by harnessing exhaust heat energy which would otherwise be wasted.

Air borne radar can pick up the extended snorkel tube of a submarine and bring the "hunter-killer" team into action. If the submarine dives deep enough, visual and radar beams are no longer effective in determining where it is. Then, sono buoys can be dropped into the sea to divulge its position. These are small radio broadcasting sets, in metal containers, which drop a sensitive microphone into the water and extend a whip antenna above the surface. They can "hear" the sounds of a sub's propellers or engine and transmit that data.

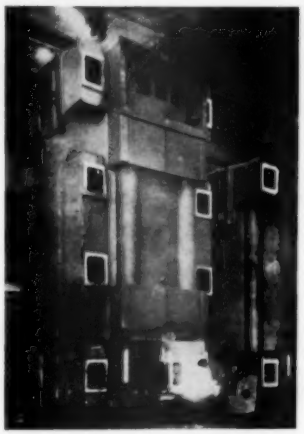
If the submarine remains quiet, magnetic airborne detection (MAD) can be used to reveal its position. The blimp is invaluable in tracking and pinpointing the target until destroyers and planes arrive to make the "kill" with bombs, depth charges, torpedoes or hedgehogs.

A Welded Gargantua

Requiring more than 3000 ft of welds, this giant generator stator receives its finishing arc welding touches at the General Electric Co.'s Schenectady, N. Y., Works.

Huge stator frames like this are welded in three positions. In the horizontal and vertical positions AWS-E6010 electrodes are used. In the third position, the frame is placed horizontally on a set of Ransome turning rolls and rotated so that most of the welding can be done flat to take advantage of the greater deposition rates of large-size electrodes. For this flat welding AWS-E6020 welding electrodes are used.

In the photo, a chipper is shown cleaning off a weld on top of the 168,200-lb monster while a welder, using a 500-amp a-c arc welder, works below.



ABS Meeting

The Semiannual Meeting of the Board of Managers of the American Bureau of Shipping was held July 29th in the board room of the Bureau at 45 Broad St., New York City. President Walter Green reported:

"There now exist in class with the American Bureau of Shipping 8494 vessels of 37,153,772 gross tons, of which about 20% are temporarily inactive, compared to 17% six months ago. To this figure there will be added 759 vessels completed or under construction on July 29th in United States and foreign shipyards, these aggregating 3,511,350 tons, making a grand total of 9253 vessels of 40,665,122 gross tons. While a substantial percentage of these vessels are foreign owned and/or registered, the large majority fly the American flag. These figures include seagoing tonnage, Great Lakes and river craft, both self-propelled and nonpropelled."

PERSONNEL

Pierce Named Executive Vice-President of New York Ship

The election of Harry W. Pierce to the post of executive vice-president and director has been announced by New York Shipbuilding Corp., Camden, N. J.

Mr. Pierce, who was president of the AMERICAN WELDING SOCIETY in 1950–51, has been assigned responsibility for operations of the company shipyard following the resignation of Thomas H. Bossert as president.

Mr. Pierce, a long-time specialist in ship welding problems, was graduated from the U. S. Naval Academy in 1922 and received a masters degree from Massachusetts Institute of Technology in 1926. From 1930 to 1947 he served as welding engineer for New York Ship, then became assistant to the president. He was elected vice-president of the company in 1950.

During World War II, Mr. Pierce administered New York Ship's landing craft program in which nearly 150 tank and infantry landing craft were delivered within eight months of the signing of the first contract. For this and other Navy work he was awarded the Commendation Certificate of the Bureau of Ships. In 1947 he was granted a four-month leave of absence to assist in a study of the Japanese shipbuilding industry for the War Department. He has served on many advisory committees dealing with welding problems in ship construction and related matters.

In addition to his membership in the AMERICAN WELDING SOCIETY, Mr. Pierce is a member of the Society of Naval Architects and Marine Engineers, the American Society for Testing Materials, the Engineers Club of Philadelphia and the Maritime Society of th Port of Philadelphia.

Air Reduction Announces Advertising Changes

G. T. Van Alstyne AWS has been appointed director of advertising and publicity of Air Reduction Co., Inc., it was announced recently by C. D'W. Gibson, AWS, vice-president in charge of sales.

George M. Worden, recently with Hill and Knowlton, Inc., public relations counsel, rejoins the company as assistant to the director.

In commenting on the establishment of advertising and publicity as corporate functions, Mr. Gibson said, "This organizational change is in keeping with the company's divisional setup and is designed to give us the maximum value for each dollar of advertising."

Mr. Van Alstyne is succeeded as advertising manager of Air Reduction Sales Co. by A. V. Scherer, formerly advertising manager of the Ohio Chemical & Surgical Equipment Co. division.

Mr. Scherer is succeeded at Ohio Chemical by Henry W. Beck.

The men involved will have their headquarters in New York with the exception of Mr. Beck, who will be located at Madison, Wis.

Helmut Thielsch Joins Eutectic

The appointment of Helmut Thielsch, formerly of the Welding Research Council, to the position of Director of Applied Welding Engineering at Eutectic Welding Alloys Corp. of Flushing, N. Y., was announced recently by R. D. Wasserman, president of the company.

Mr. Thielsch spent the past three years in charge of preparation of critical correlated literature reviews for research investigators and interpretive engineering reports for practical engineers.

Mr. Thielsch has been the author or co-author of over 30 scientific and technical papers on subjects pertaining primarily to the physical and welding metallurgy of mild, alloy and stainless steels, bulge testing, surface evaluation of metals, electron microscopy, etc.

Weldwire Company, Inc.

formerly Weldit Wire Co. Inc.

WIRE FOR WELDING

Weldspool Electrode Wire

FOR INERT GAS WELDING
(Chemically processed-precision wound)

For "QUALITY CONTROLLED" Welds on:

ALUMINUM
STAINLESS STEELS
ALLOY STEELS
BRONZES
CAST IRON or
SPECIAL ALLOYS

USE "WELDSPOOL" ELECTRODE WIRE or "WELDBEST" ELECTRODES

Weldbest Electrodes

FOR MANUAL ARC WELDING

WELDWIRE COMPANY, INC.
N. W. Cor. Emerald & Hagert Sts.
Philadelphia 25, Pa.
PHONE: Garfield 3-1232

NOW!

LOOK TO REXWELD HARD SURFACING ROD

IT'S BETTER THESE WAYS:

CUT WELDING TIME

1. Rexweld builds up and holds on an edge better! This means less welding time is required.

INCREASE PRODUCTION

2. Rexweld flows more readily on flat surfaces! In machine gas welding operations valve companies have reported an increase in production per shift using Rexweld.

LESS POROSITY TENDENCY

3. Rexweld has less tendency for porosity because of its smoother flowing and better wetting properties.

BETTER WEARING QUALITY

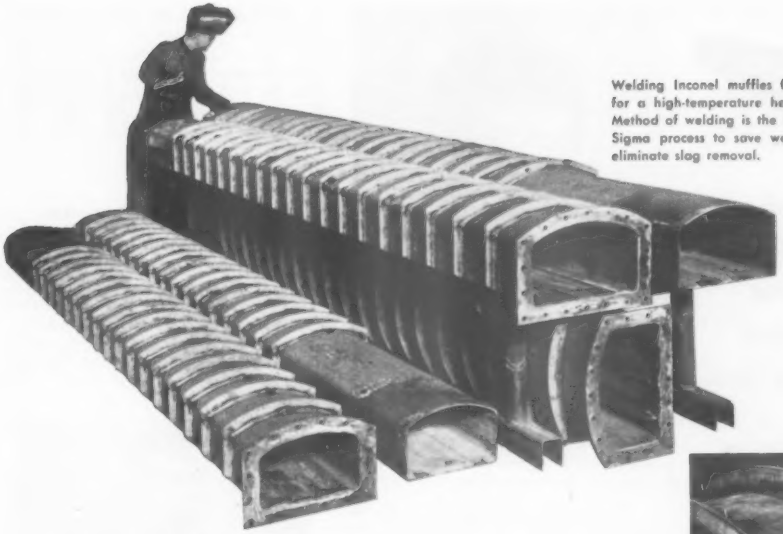
4. Tests show Rexweld has better wearing qualities.

Hundreds of satisfied users, manufacturing such products as valves, oil pump parts, mixer shafts attest to Rexweld's ability to do a better job . . . at less cost! Rexweld is available in a wide range of grades to meet all requirements. Then too, Rexweld meets Government specifications. If you use hard surfacing rod, be sure you check Rexweld . . . it'll save you time and money.

CRUCIBLE REXWELD HARD SURFACING ROD

52 years of Fine steelmaking

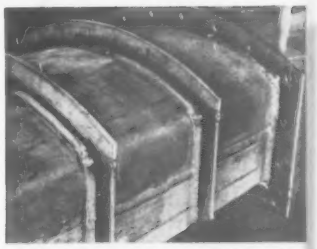
CRUCIBLE STEEL COMPANY OF AMERICA, GENERAL SALES OFFICES, OLIVER BUILDING, PITTSBURGH, PA.



Welding Inconel muffles for use in furnaces for a high-temperature heat-treating process. Method of welding is the inert gas metal arc Sigma process to save welding time and to eliminate slag removal.

Class "A" welding job for "D"-type muffles

...THANKS TO INCO'S COMPLETE LINE OF WELDING MATERIALS



Close-up of a muffle showing welded construction. Note: Longitudinal weld on side is at midpoint instead of at corner to eliminate unfavorable stresses.

The completeness of Inco's line of welding materials made this job easy (and more profitable) for The Thornton Company of Cleveland.

They had an order for eighteen high-temperature service muffles. The material specified was Inconel®.

As the photographs show, muffles are of the "D"-type. 3/8-inch Inconel plate and Inconel stiffeners are used. Corner welds are avoided to eliminate unfavorable stresses. Careful fitting of the stiffeners is necessary to prevent warpage during the welding.

With Inco's new "62" Inconel welding wire, The Thornton Company was able to do the job by inert gas metal arc welding, which permitted faster deposition and eliminated slag removal.

* * *

The completeness of the Inco line of welding material permitted this company to use the most effective fabrication method. It may enable you to improve your production (or repair or salvage operations) also.

To help you determine which materials are recommended for specific applications, we have prepared "Inco Welding Materials Guide." For your copy just mail this coupon.

"62" Inconel welding wire is furnished in cut lengths and on disposable spools. Today, however, it, like the other Inco Nickel Alloy Welding materials, is on extended delivery because so much is going into defense operations. So it will pay you to anticipate your needs, ordering well in advance of work schedules.

The International Nickel Company, Inc.
67 Wall Street, New York 5, N. Y.

Please send me the free INCO WELDING MATERIALS GUIDE.

Name_____

Address_____

City_____ State_____

WJ-9-52

INCO TRADE MARK

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street, New York 5, N. Y.

If you do AC Bronze Welding, check these Advantages

- No snuff outs
- Easy striking
- Wear resistant
- Corrosion resistant
- Welds dissimilar metals
- High strength
- High ductility
- Can be used with AC or DC

You get them all with AMPCO-TRODE* 'AC' Coated Aluminum Bronze Electrodes

THESE Ampco-Trode "AC" advantages mean lower welding costs for you—better, faster jobs—less trouble. Besides the advantages listed you also get a smooth bead that feather-edges perfectly into the base metal — whether it's used on cast iron, malleable iron, bronzes, some nickel alloys, or dissimilar metals.

Moreover, Ampco-Trode "AC" beads are free from porosity and surface pitting. Spatter loss is low, too.

Ampco-Trode "AC" is available in 5 grades having Brinell hardness ranging from 135 to 300, tensiles from 77,000 to 90,000 psi, and yield strengths from 35,000 to 69,000 psi.

For additional information about versatile, money-saving Ampco-Trode "AC" electrodes call your nearby Ampco distributor or write us.

*Reg. U. S. Pat. Off.

AMPCO METAL, INC.
MILWAUKEE 46, WISCONSIN
West Coast Plant: Burbank, California
It's Production-Wise to Ampco-ize!

Mr. Thielsch's experience also includes that of Secretary of High-Alloys Committee, Welding Research Council; Research Engineer at Lukens Steel Co.; metallurgist with Black, Sivalls, Bryson, Inc.; and engineer with the Allis-Chalmers Manufacturing Co. He is a member of the American Society of Mechanical Engineers, American Chemical Society, American Society of Metals, Eta Kappa Nu and Sigma Xi.

Mr. Thielsch will be a member of the research team at Eutectic.

Woods Joins Republic Hardfacing

Ray A. Mentel, recently with Perfection Stove Co., is now Vice-President and General Manager of Republic Hardfacing Corp. of Bedford, Ohio. Mr. Mentel announces that Mr. Gorham W. Woods has joined Republic Hardfacing Corp. as Engineer. Mr. Woods will be in charge of a new division, namely, the Industrial Hardfacing Division, and will be available for consultation on problems of heat and wear resistance.

Mr. Woods is a pioneer in the hardfacing field. During the past seven years he was development engineer for Lincoln Electric Co. where he initiated their hardsurfacing program and produced a number of hardsurfacing electrodes and fluxes.

A graduate of the Rice Institution of Houston, Tex., in Engineering, he joined the engineering staff of Hughes Tool Co. where he worked for 21 years, devoting a major portion of his time to problems of metal wear caused by friction, heat and corrosion. He was in charge of the development of special surfacing alloys required for the protection of the drills used for drilling oil wells and he specified the surfacing procedures.

Mr. Woods is a registered professional engineer in Ohio, and has been active in the AMERICAN WELDING SOCIETY. He has a number of patents on welding material and procedures. He is also a member of the American Society for Metals and Tau Beta Pi Fraternity.

Robert Benwell Promoted

Robert Benwell has been appointed Superintendent of the Structural Department of Yale & Towne's Philadelphia Division. His duties in this new position will include the processing and fabrication of structural members for both light- and heavy-duty materials handling equipment.

In heading up the Structural Department, Mr. Benwell will coordinate the flow of steel from the layout tables through the many flame-cutting, assembling, welding and finishing operations in a progressive manner.

Mr. Benwell joined the Yale & Towne organization as General Welding Foreman in 1951, bringing with him many years of welding and fabricating experience. He was formerly associated with General, Motors Electromotive Division in La-Grange, Ill., as Welding Supervisor. Mr. Benwell is an active member of the AWS.

ANNUAL DINNER

Ball Room-Bellevue Stratford
Philadelphia, Pa.
October 23rd-7:15 P.M.

Roast Beef
Medal Awards
Door Prizes
Professional Entertainment 1½ hrs.
Orchestra
Price $10.00 per person

Reservations: K. Wm. Ostrom, c/o K. Wm. Ostrom & Co., 3717 Filbert Street Philadelphia 4, Pa.

TENTATIVE PROGRAM

AMERICAN WELDING SOCIETY

33rd National Fall Meeting

week of October 19, 1952

THE BELLEVUE-STRATFORD, PHILADELPHIA, PA.

Welding and cutting demonstration will be featured at the National Metal Exposition held during the week at the Convention Halls

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TECHNICAL SESSIONS

All Technical Sessions will positively start on time.

No Stenotype Reporter—Members desiring to discuss papers are urgently requested to prepare discussion in writing in advance of the meeting and to send copies to Headquarters, as those preparing written discussion will be given preference at the sessions. Members and guests giving extemporaneous discussion at meeting should forward a written discussion as soon as possible after the meeting.

MONDAY MORNING, OCTOBER 20th

Rose Garden

10:00 A.M.—AWARD OF PRIZES

10:30 A.M.—ADAMS LECTURE

Chairman—CHARLES H. JENNINGS
President, American Welding Society

Co-Chairman—H. R. MORRISON
Chairman, Convention Committee

The Welding and Brazing of Titanium Alloys
by C. B. VOLDRICH, Battelle Memorial Institute

MONDAY AFTERNOON, OCTOBER 20th—2:00 P.M.

Three Simultaneous Sessions

1—FABRICATING PROCEDURES

Rose Garden

Chairman—F. L. PLUMMER
Hammond Iron Works

Co-Chairman—H. C. CAMPBELL
Arcos Corp.

Fusion Welding Techniques for Jet Aircraft Components
by ARNOLD S. ROSE and MORTON A. BRAUN, I. T. E. Circuit Breaker Co.

Should Preheat Be Substituted for High-Temperature Stress Relief in the Codes?
by E. PAUL DeGARMO, University of California

Chromium - Recovery During Submerged Arc Welding
by JAMES G. KERR and DAVID A. ELMER, C. F. Braun & Co.

2—RESISTANCE WELDING

North Garden

Chairman—T. EMBURY JONES
Precision Welder & Machine Co.

Co-Chairman—J. J. MacKINNEY
Budd Co.

Corrosion of Structural Spot Welds
by B. KARNISKY, E. P. GRUCA and E. KINELSKI, Pullman-Standard Car Mfg. Co.

Maintenance of Resistance Welders in High-Speed Assembly Lines
by JAMES F. SALATIN and O. D. ETCHISON, Delco-Remy Division, General Motors

Magnetic Force Welding
by MYRON ZUCKER, Myron Zucker Engineering Co. and G. Cubitt-Smith, Technical Consultant

3—HARD FACING AND FLAME HARDENING

South Garden

Chairman—E. H. ROPER
Air Reduction Sales Co.

Co-Chairman—R. A. GUENZEL
Southern Oxygen Co.

Hard Facing Alloys of the Chromium Carbide Type
by HOWARD S. AVERY and HENRY J. CHAPIN, American Brake Shoe Co.

Selection and Evaluation of Methods of Hard Facing
by JACK J. BARRY, Air Reduction Sales Co.

Flame Hardening of Large-Diameter Thin-Wall Cylindrical Shells
by G. A. WEBER, M. W. Kellogg Co.

MONDAY EVENING, OCTOBER 20th—6:00 P.M.

President's Reception

Burgundy Room

TUESDAY MORNING, OCTOBER 21st—9:30 A.M.

Three Simultaneous Sessions

4—RESISTANCE WELDING

North Garden

Chairman—JACK OGDEN
Fisher Body Div., General Motors

Co-Chairman—K. W. OSTROM
K. W. Ostrom & Co.

The Expression of Spotweld Properties
by JULIUS HEUSCHKEL, Westinghouse Electric Corp.

Temperature Distribution During Flash Welding of Steel—Part II
by ERNEST F. NIPPES, WARREN F. SAVAGE, JOHN J. McCARTHY and SHERIDAN S. SMITH, Rensselaer Polytechnic Institute

Spot Welding of Titanium Alloy Sheet
by M. L. BEGEMAN, EDWIN H. BLOCK, Jr., and FRANK W. McBEE, Jr., The Univerity of Texas

Spot Welding Magnesium with Three-Phase Low-Frequency Equipment
by DEAN L. KNIGHT and PAUL THORNE, National Electric Welding Machines Co., and PAUL KLAIN, Dow Chemical Co.

5—WELDABILITY

South Garden

Chairman—R. E. SOMERS
Bethlehem Steel Co.

Co-Chairman—A. B. GORDON
Linde Air Products Co.

Further Studies of the Crack Sensitivity of Aircraft Steels
by A. W. STEINBERGER and J. STOOP, Curtiss Wright Corp., Propeller Div.

Effect of Geometry on Stresses in Circular Patch Specimen
by ALAN V. LEVY and HARRY E. KENNEDY, University of California

Evaluation of the Circular-Patch Weld Test
by JOHN E. HOCKETT and L. O. SEABORN, University of California

Relationship of Welding Technique to Penetration and Dilution
by CLARENCE E. JACKSON and ARTHUR E. SHRUBSALL, Union Carbide and Carbon Research Laboratories, Inc.

6—STRUCTURAL

Rose Garden

Chairman—LAMOTTE GROVER
Air Reduction Sales Co.

Co-Chairman—I. E. BOBERG
Chicago Bridge & Iron Co.

The Behavior of Welded Portal Frames
by E. R. JOHNSTON, LYNN S. BEEDLE, Fritz Engineering Laboratory, Lehigh University, and J. M. RUZEK, C. F. Braun & Co.

Residual Stress and the Compressive Strength of Steel
by LYNN S. BEEDLE, A. W. HUBER, Fritz Engineering Laboratory, Lehigh University, and BRUCE G. JOHNSTON, University of Michigan

How to Save Cost by Designing for Structural Welding
by ALFRED E. PEARSON, The Ingalls Iron Works Co.

Distortion Control in Structural Fabrication
by GORDON CAPE and LLEWELLYN JEHU, Dominion Bridge Co., Ltd.

TUESDAY AFTERNOON, OCTOBER 21st—2:00 P.M.

Three Simultaneous Sessions

7—WELDABILITY

South Garden

Chairman—E. M. MacCUTCHEON Jr.
Bureau of Ships, Navy Department

Co-Chairman—L. J. LARSON
Allis-Chalmers Mfg. Co.

The Effect of Strain Rate on Twinning and Brittle Fracture in Low-Carbon Steel
by D. ROSENTHAL and C. C. WOOLSEY, Jr., University of California

Interpretation of Test Data Regarding Brittle Strength and Transition Temperature of Structural Steel
by W. C. HOELTJE and N. M. NEWMARK, University of Illinois

Factors Affecting the Resistance of Pressure Vessel Steels to Repeated Overloading
by ROBERT D. STOUT, JOHN H. GROSS and SCHILLINGS TSANG, Lehigh University

8—RESISTANCE WELDING

North Garden

Chairman—J. H. COOPER
The Taylor-Winfield Corporation

Co-Chairman—W. G. FETTER
P. R. Mallory & Co.

Quality Control of Resistance Welding by Statistical Methods
by J. F. RADFORD and R. K. WALDVOGEL, Crosley Division, Avco Mfg. Corp.

Contact Resistance
by WILLIAM B. KOUWENHOVEN, The John Hopkins University and CLARENCE W. LITTLE, Jr., The Allis-Chalmers Company

New Multispot Control Provides Increased Welding Production with Limited Power Supply
by CLAUDE R. WHITNEY, Jr., Square D Co.

9—BRAZING AND BRONZE WELDING

Rose Garden

Chairman—J. J. VREELAND
Chase Brass & Copper Co.

Co-Chairman—L. H. HAWTHORNE
Revere Copper & Brass, Inc.

New Aspects in Surface Alloying in Brazing and Related Techniques
by DR. ROBERT HUMPHREY and RENE D. WASSERMAN, Eutectic Welding Alloys Corp.

Strength Joints to Steel with Aluminum Bronze Filler Metals
by WILLIS G. GROTH, Ampco Metal, Inc.

Vacuum Brazing of Clad Steels
by R. C. BERTOSSA, Chicago Bridge & Iron Company

TUESDAY AFTERNOON, OCTOBER 21st—4:30 P.M.

EDUCATIONAL LECTURE SERIES

Rose Garden

Chairman—GILBERT E. DOAN

The Inert-Gas Metal-Arc-Welding Process
by WALTER H. WOODING, Philadelphia Naval Shipyard

TUESDAY EVENING, OCTOBER 21st—6:30 P.M.

Section Officers Dinner and Meeting

Junior Room

FLOWLINE
TRADE MARK
WELDING FITTINGS
Stainless Steels, Monel, Nickel
2120
3" SCH. 10
FLOWLINE
.120" WALL
304
2240
4" SCH. 10
FLOWLINE
.120" WALL
316
3000 Stock Items Made by Corrosion-Resistant Specialists
FLOWLINE Welding Fittings are made and stocked by an organization having greater experience with corrosion-resistant metals than any other fittings manufacturer. The purpose of this specialization is to make it practicable for users of corrosion-resistant piping to have the full efficiency and economy of welded construction—in design, installation, operation and maintenance.
Welded construction permits greatest freedom in designing the layout. The initial cost is usually less than for other types of installations. The system uses less space, is lighter, stronger, and can be assembled and put into service faster. It is permanently leak-proof, provides best flow characteristics, has longer life, and can be changed and added to more easily and economically.
The most effective corrosion-resistant welded system can be obtained by using FLOWLINE Fittings—tees, ells, stub ends, reducers, returns, and caps. Normally stocked at strategic points in Schedules 10, 40, and 80 (Schedule 5 also available) — sizes ½" through 12"—in stainless steel types 304, 316, 347; Monel and Nickel. They are handled by distributors throughout the country who are experts in corrosion-resistant piping.
WELDING FITTINGS CORP.
NEW CASTLE, PENNSYLVANIA
World's Largest Manufacturer of Stainless Welding Fittings

WEDNESDAY MORNING, OCTOBER 22nd

PLANT VISIT—2 OPTIONAL TRIPS—9:00 A.M.

(Open only to citizens or visitors having necessary credentials)
Philadelphia Naval Shipyard or Naval Air Material Center
or
Steam Division, Westinghouse Electric Corporation, Lester, Pa.

Three Simultaneous Sessions—9:30 A.M.

10—NONFERROUS

North Garden

Chairman—O. B. J. FRASER
International Nickel Co.

Co-Chairman—J. R. HUNTER
Westinghouse Electric Corp.

The Semiautomatic Inert-Gas Metal-Arc Welding of Aluminum Alloys
by CHARLES T. GAYLEY, JOSEPH R. GIRINI and WALTER H. WOODING, Industrial Test Laboratory, Philadelphia Naval Shipyard

Welding 90-10 Cupro-Nickel by the Inert-Gas-Shielded Arc Processes
by L. H. HAWTHORNE, Revere Copper and Brass, Inc.

Weld Cracking of Aluminum Alloys
by JAMES D. DOWD, Aluminum Company of America

11—WELDABILITY

Rose Garden

Chairman—L. C. BIBBER
United States Steel Co.

Co-Chairman—R. H. LAMBERT
Captain, USN

Relation of Preheating to Low-Temperature Cooling Rate Embrittlement and Microcracking
by A. E. FLANIGAN and T. MICLEU, University of California

Initiation and Propagation of Brittle Fracture in Structural Steels
by PETER P. PUZAK, EARL W. ESCHBACHER and WILLIAM S. PELLINI, Naval Research Laboratory

The Continuous Cooling Transformation of Weld Heat-Affected Zones
by W. R. APBLETT, Jr., L. K. POOLE and W. S. PELLINI, Naval Research Laboratory

The Determination of Optimum Conditions for the Automatic Welding of Hardenable Steels
by C. B. McKINSEY and J. F. COLLINS, Union Carbide & Carbon Research Laboratories, Inc.

12—TITANIUM ALLOYS

South Garden

Chairman—COLONEL B. S. MESICK
Ordnance Corps, Watertown Arsenal

Co-Chairman—CARL E. HARTBOWER, Watertown Arsenal

Practical Aspects of Arc Welding Titanium Alloys
by J. J. CHYLE and IVAN KUTUCHIEF
A. O. Smith Corporation

The Effects of Fe, Mn, Cr and Mo on Welds in Titanium
by G. E. FAULKNER, G. B. GRABLE and C. B. VOLDRICH, Battelle Memorial Institute

An Investigation of the Thermal Cycles Adjacent to Arc Welds in ½ Inch Titanium Plate
by E. F. NIPPES, J. M. GERKEN and B. W. SCHAAF, Rensselaer Polyechnic Institute

Contaminants in Welding Titanium
by R. W. HUBER and THOMAS R. GRAHAM, Bureau of Mines

WEDNESDAY AFTERNOON, OCTOBER 22nd—2:00 P.M.

Three Simultaneous Sessions

13—WELDABILITY

North Garden

Chairman—R. D. THOMAS, Jr.
Arcos Corp.

Co-Chairman—C. B. JENNI
General Steel Castings Corp.

Embrittlement of High-Strength Ferritic Welds
by PETER P. PUZAK and WILLIAM S. PELLINI, Naval Research Laboratory

Temper Brittleness in Low-Alloy Steel Weld Metal
by RICHARD P. WENTWORTH and HALLOCK C. CAMPBELL, Arcos Corp.

The Effects of Electrodes and Welding Conditions on the Ductility of Arc-Welded Mild Steels
by ERNEST F. NIPPES and ALEXANDER LESNEWICH, Rensselaer Polytechnic Institute

14—NONFERROUS

South Garden

Chairman—G. O. HOGLUND
Aluminum Company of America

Co-Chairman—J. S. DOUGLASS
Linde Air Products Co.

The Strength and Ductility of Welds in Aluminum Alloy Plate
by F. M. HOWELL and F. G. NELSON, Jr., Aluminum Research Laboratories

Factors Which Determine the Performance of Aluminum Alloy Weldments
by W. R. APBLETT, JR., C. R. FELMLEY and W. S. PELLINI, Naval Research Laboratory

Welding and Forming of Titanium
by FRANCIS H. STEVENSON, Aerojet Engineering Corp.

15—MAINTENANCE AND GAS CUTTING

Rose Garden

Chairman—H. V. INSKEEP
Linde Air Products Co.

Co-Chairman—A. M. GARCIA
Morris, Wheeler & Co., Inc.

Wear and Operation Problems in Maintenance
by FRANK J. GAYDOS, United States Steel Co., Gary Works

Effect of Oxygen Cutting on Alloy Steel (Armor Plate)
by F. C. SAACKE, Air Reduction Co., Inc.

WEDNESDAY AFTERNOON, OCTOBER 22nd—4:30 P.M.

EDUCATIONAL LECTURE SERIES

Rose Garden

Chairman—GILBERT E. DOAN

The Inert-Gas Metal-Arc Welding Process
by WALTER H. WOODING, Philadelphia Naval Shipyard

WEDNESDAY EVENING, OCTOBER 22nd

6:30 P.M.

National Officers

Dinner and Meeting

Pink Room

8:00 P.M.

WRC University

Research Conference

South Room

THURSDAY MORNING, OCTOBER 23rd—9:30 A.M.

Three Simultaneous Sessions

16—INERT ARC WELDING

North Garden

Chairman—C. I. MacGUFFIE
General Electric Co.

Co-Chairman—K. L. WALKER
Foster Wheeler Corp.

A Comparison of Shielding Mixtures for Gas-Shielded Arc Welding
by J. WARDEN CUNNINGHAM, and HARRY C. COOK, Air Reduction

Production Welding of Mild and Low-Alloy Steels by Gas-Shielded Arc Welding
by GILBERT ROTHSCHILD and JOHN H. BERRYMAN, Air Reduction Co., Inc.

Porosity in Mild Steel Weld Metal
by DONALD WARREN, E. I. du Pont de Nemours & Co., Inc., and R. D. STOUT, Lehigh University

17—BRAZING

South Garden

Chairman—A. N. KUGLER
Air Reduction Co., Inc.

Co-Chairman—A. M. SETAPEN
Handy & Harman

Advanced Information for the Brazing Operator
by E. F. DAVIS, Westinghouse Electric Corp.

Joint Design for Brazing
by W. J. VAN NATTEN, General Electric Co.

Technical Aspects of Soldering Practices
by R. M. MacINTOSH, Tin Research Institute, Inc.

Production Brazing
by J. R. WIRT, Delco-Remy Division, General Motors Corp.

18—MARINE CONSTRUCTION

Rose Garden

Chairman—DAVID P. BROWN
American Bureau of Shipping

Co-Chairman—A. A. HOLZBAUR
Sun Shipbuilding & Dry Dock Co.

New Rules for Welding Low-Alloy Ferritic Pipe Material
by COMMANDER CHARLES F. PERRY, USCG

Evaluation of Brittle Failure Research
by PAUL FFIELD and ED SWEENEY, Bethlehem Steel Co.

An Investigation on Peening
by P. L. CALAMARI, F. J. CRUM and G. W. PLACE, American Bureau of Shipping

THURSDAY AFTERNOON, OCTOBER 23rd

2:00 P.M.

Clover Room

Business Meeting

3:00 P.M.

Junior Room

Board of Directors Meeting

THURSDAY EVENING, OCTOBER 23rd

7:00 P.M.

Annual Dinner

Ball Room

FRIDAY MORNING, OCTOBER 24th—9:30 A.M.

Three Simultaneous Sessions

19—PIPE

North Garden

Chairman—E. R. SEABLOOM
Crane Co.

Co-Chairman—A. J. ERLACHER
United Engineers & Constructors

Pipe Welding in the Petroleum Refining Industry
by ALBERT W. ZEUTHEN, Socony Vacuum Oil Co.

The Arc Welding of Low Chromium-Molybdenum Steel Pipe
by J. BLAND, L. J. PRIVOZNIK and F. J. WINSOR, Standard Oil Company of Indiana

Effect of Stresses and Stress Relief on the Bursting Strength of Circumferentially Welded Cylinders
by L. J. PRIVOZNIK Standard Oil Company of Indiana

Inert Arc Welding Techniques for Eliminating Backing Rings in Piping
by R. A. MUELLER and N. B. ROOT, Crane Co.

20—INERT ARC

South Garden

Chairman—C. D. EVANS
International Harvester Co.

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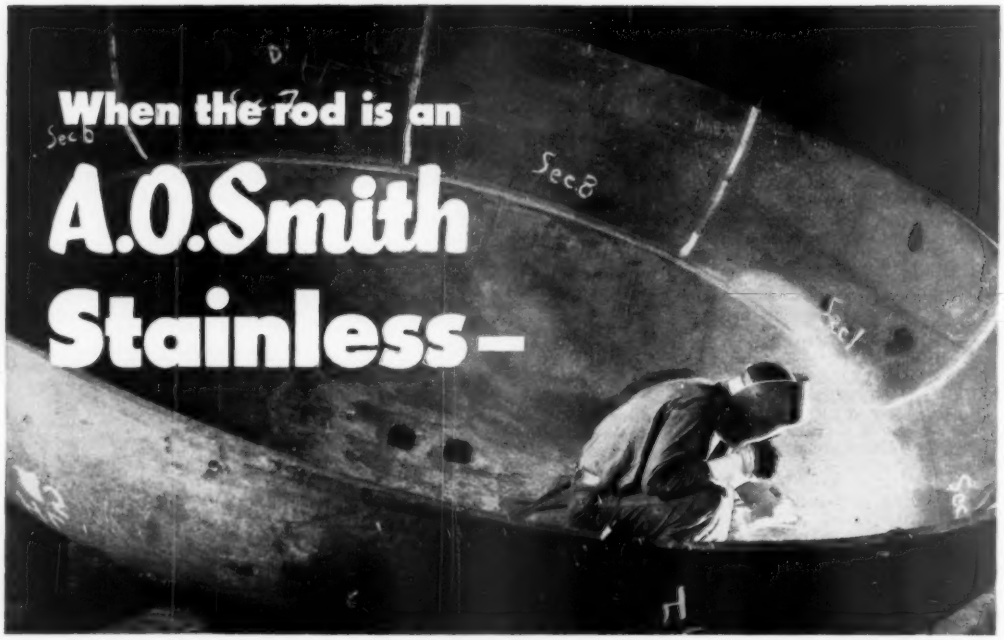

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SECTION NEWS AND EVENTS

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Election of Officers

Birmingham, Ala.—The *Birmingham* Section announces the election of the following officers for 1952–53:

Chairman—D. H. Curry.
First Vice-Chairman—E. D. McCauley.
Secretary-Treasurer—E. R. Owens, Tennessee Coal, Iron & R. R. Co., Enslay, Ala.
Chairman, Membership Committee—J. E. Durstine, Lincoln Electric Co.
Chairman, Program Committee—E. D. McCauley, American Cast Iron Pipe Co.
Technical Representative—A. E. Pearson, Ingalls Shipbuilding Corp.

Tour

Bradford, Pa.—Following a swiss steak dinner at the Marconi Outing Club on May 19th, 89 of the members of the *Olean-Bradford* Section toured the Struthers-Wells Plant in Warren, Pa.

Election of Officers, Tour

Bradford, Pa.—The *Olean-Bradford* Section held an election of officers at its June 16th dinner meeting held at the Bradford, Pa., YWCA, with the following results:

Chairman—Charles Schuman, Dresser Mfg. Co., Bradford, Pa.
First Vice-Chairman—George McMullen Clark Bros., Olean, N. Y.
Second Vice-Chairman—Ralph Sutherland, Dresser Mfg. Co.
Secretary—Guy Whipple, Kendall Refinery, Bradford, Pa.
Treasurer—Anthony Lorenzini, Daystrom Furniture, Olean, N. Y.

Prior to the dinner and meeting a tour was made of the Kendall Oil Refinery starting at 5 P.M. At their Sales Clinic a briefing was given and charts were shown on the processing of the crude oil to the varied finished products. Guided groups were then taken through the plant and shown the actual processing of the crude oil that flows through miles of welded pipes and pressure vessels of all descriptions.

At the meeting, C. H. Jennings, AWS President, spoke on new Section membership and the next national meeting.

Cleveland Officers

Cleveland, Ohio.—The *Cleveland* Section announces the election of the following officers for 1952–53:

Chairman—Frank G. Flocke, The Thornton Co.
First Vice-Chairman—Lewis Gilbert, Industry & Welding.
Second Vice-Chairman—J. Robert Henry, Lakewood.
Secretary-Treasurer—J. F. Wagner, The Burdett Oxygen Co.
Chairman, Membership Committee—John Rogos, Jr., Lakewood.
Chairman, Program Committee—Lewis Gilbert.
Technical Representative—Dave Gerould, Williams & Co. Inc.

Columbus Officers

Columbus, Ohio.—The *Columbus* Section announces the election of the following officers for 1952–53:

Chairman—Howard B. Cary, Marion Power Shovel.
Vice-Chairman—Melvin C. Clapp, Battelle Memorial Institute.
Secretary—Arthur P. Bruce, American Blower Corp.
Treasurer—Joseph E. Brockmeyer, Surface Combustion Co.
Directors—R. A. Zimpfer, R. A. Bowers, J. Kidwell, Blaine Harrington and A. J. Williams.

Dallas Officers

Dallas, Tex.—The *Dallas* Section announces the election of the following officers for 1952–53:

Chairman—R. W. McClain.
First Vice-Chairman—J. P. Viglini.
Second Vice-Chairman—M. E. Eliot.
Secretary-Treasurer—W. A. Thompson, Wyatt Metal & Boiler Works.
Asst. Sec.—R. A. Banks, Jr.
Chairman, Membership Committee—Val J. Boyd.
Chairman, Program Committee—J. P. Viglini.
Technical Representative—A. D. Travis.

Dayton Officers

Dayton, Ohio.—The *Dayton* Section announces the election of the following officers for 1952–53:

Chairman—H. Fred Schulmeister.
First Vice-Chairman—Glyn O. Williams.
Secretary—M. K. Good.
Treasurer—George Theriault.
Chairman, Membership Committee—Robert H. Coburn.
Chairman, Program Committee—Glyn O. Williams.
Technical Representative—Albert J. Mealy, Air Reduction Sales Co.

Election of Officers

Grand Rapids, Mich.—The *Western Michigan* Section announces the election of the following officers for 1952–53:

Chairman—Carl Van Loo.
First Vice-Chairman—Glenn Hickock.
Second Vice-Chairman—Paul W. Wagner.
Secretary—Gordon Hill.
Treasurer—Chester H. Vorrhorst.

Houston Officers

Houston, Tex.—The *Houston* Section announces the election of the following officers for 1952–53:

Chairman—Ben H. Allen, Mosher Steel Co.
First Vice-Chairman—W. H. Greer, Southwestern Laboratories.
Secretary-Treasurer—H. H. Wehner, Hughes Tool Co.
Chairman, Membership Committee—G. F. Vietor, Jr., Air Reduction Magnolia Co.
Technical Representative—W. G. Gumm, Linde Air Products Co.

Los Angeles Officers

Los Angeles, Calif.—The *Los Angeles* Section announces the election of the following officers for 1952–53:

Chairman—Herbert K. Clemens.
First Vice-Chairman—Franklin R. Drahos.
Secretary-Treasurer—Francis V. McGinley.
Chairman, Membership Committee—J. R. Van Rensselaer, District Steel & Equipment Co.
Co-Chairman—John A. Toland, Research Welding & Engineering Co.
Chairman, Program Committee—Franklin R. Drahos.
Technical Representative—Charles W. Johnson.

Election of Officers

Minneapolis, Minn.—The *Northwest*

Section announces the election of officers as follows for 1952-53:

Chairman—Warren F. Logemann.
First Vice-Chairman—A. H. Hanson.
Secretary-Treasurer—Lillian K. Polzin, Minneapolis Chamber of Commerce.
Chairman, Membership Committee—W. E. Coleman.
Chairman, Program Committee—A. H. Hanson.

Oklahoma City Officers

Oklahoma City, Okla.—The *Oklahoma City* Section announces the election of the following officers for 1952-53:

Chairman—W. W. Littlefield, Air Reduction Magnolia.
First Vice-Chairman—James N. Thompson.
Exec. Vice-Chairman—William Klein, Sr.
Secretary—L. L. Stewart, Harris Calorific Sales Co.
Treasurer—Lon E. Erickson.
Chairman, Membership Committee—L. P. Stilwell.
Chairman, Program Committee—Ed Hotchkiss.
Technical Representative—R. K. Hughes.

Richmond Officers

Richmond, Va.—The *Richmond* Section announces the election of officers for 1952-53 as follows:

Chairman—W. C. Collier, Collier Bros. Machine Works.
First Vice-Chairman—Vaughan E. Calder, Jr.
Second Vice-Chairman—W. B. Jones.
Secretary—W. Wayne Utley.
Treasurer—Fred T. Mayers.
Chairman, Membership Committee—W. B. Goode, Jr.
Technical Representative—Vaughan E. Calder, Jr.

Salt Lake City Officers

Salt Lake City, Utah.—The *Salt Lake City* Section announces the election of officers for 1952-53 as follows:

Chairman—J. R. Jones.
First Vice-Chairman—Fred S. Thomas.
Second Vice-Chairman—Frank A. Hulbert.
Secretary—Darwin Christofferson.
Treasurer—Paul W. Ownby.

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Supplement to the Welding Journal, September, 1952

Should Preheat Be Substituted for High-Temperature Stress Relief in the Codes?

The author presents evidence leading to the recommendation that when using E6010 electrodes welding codes permit the substitution of 400° F preheat for 1200° F stress relief treatment

by E. Paul DeGarmo

Abstract

The results of seven independent investigations show that 400° F preheat is just as effective as 1200° F stress-relief heat treatment in improving the performance of low-carbon steel weldments, welded with AWS Type E6010 electrodes, for static and impact load conditions. This evidence is sufficient to justify revising the welding codes to permit the substitution of 400° F preheat for 1200° F stress relief under these load conditions. Such a substitution would permit more extensive use of welding.

Preliminary studies with small specimens indicate that preheat may not be quite as effective as stress relieving in the case of fatigue. However, more extensive tests with larger specimens may produce different results and find them to be equivalent. There also is need for tests to determine the relative effectiveness of 400° F preheat and 1200° F stress relief under stress corrosion conditions.

INTRODUCTION

ONE of the most unfortunate facts attendant to the use of welding for the fabrication of low-carbon steel structures is that it lowers many of the performance characteristics of the material. This is particularly true in respect to notch toughness, impact strength, fatigue strength, transition temperature and stress corrosion resistance. For many years it has been known that the original quality of the base material, with respect to these properties, can very nearly be restored by subjecting weldments to a "stress relief" heat treatment at 1100 to 1200° F. The effectiveness of this type of treatment has been so well established that it now is required for certain types of welded structures by several welding codes.

While the use of this widely accepted stress relief heat treatment has made it possible for welding to be used in more applications, its specification by the codes at the same time places serious limitations upon the use of welding. Such heat treatment costs money and thus welding must overcome a cost barrier. However, probably a more serious limitation is the fact that many structures are of such a size, or at such locations, that they cannot be given such a heat treatment in any conventional furnace. This results in many structures being designed for methods of fabrication other than welding.

During the past nine years a substantial body of evidence has been produced to indicate that the use of 400° F preheat will yield results which are, for many conditions, equivalent to those obtained with the 1100° F stress-relief heat treatment. These data have been determined by a number of independent investigators using widely differing types of tests. It is the purpose of this paper to: (*a*) Summarize these various and pre-

E. Paul DeGarmo is Professor of Mechanical Engineering, University of California, Berkeley, Calif.

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vious researches; (*b*) present the results of a new research project which has produced some further evidence regarding the relative effectiveness of 400° F preheat and 1000° F stress-relief heat treatment; (*c*) indicate to what extent there is ample evidence to justify the revision of welding codes to permit the substitution of 400° F preheat for the conventional stress-relief heat treatment; and (*d*) suggest certain areas where further investigation is needed.

PREVIOUS EVIDENCE

One of the earliest published indications of the effectiveness of 400° F preheat in improving the performance of weldments was in a paper by Doan, Stout and Frye[1] in 1943 in which it was indicated that very great improvement in bend angle could be obtained by its use.

In 1945 H. E. Kennedy[2] reported on actual tests of specimens made using preheat and 1100° F stress relief. These were bend tests on specimens 4 in. wide, made of mild steel, and each containing Unionmelt weld beads on one surface along the longitudinal centerline. The beads were notched and the specimens tested at −20°F. The results are shown in Table 1. These results indicate that 400° F preheat causes considerable improvement in weldment performance although not as much as does the 1100° F stress-relief heat treatment. There are two factors which need to be taken into account in connection with these results. One is that the length of time the stress-relieved specimens were held at 1100° F is not stated. The second is that a complete weld was not involved, but merely a bead placed upon a flat piece of steel. This last fact may have some other significance as will be pointed out later.

Table 1—Results of Bend Tests (Kennedy)

Fabrication	*Bend angle, deg*
As-welded	4
400° F preheat	25
1100° F stress relief	40

In 1947 Flanigan[3] reported some tests wherein there was again direct comparison between the effects of preheating and stress relieving. These also were bend tests conducted at −40° F, on specimens which were 6 in. wide, 9 in. long and 3/4 in. thick. A weld bead was deposited lengthwise along the centerline, using AWS Type E6010 electrode. The steel was mild, having 0.24% carbon. The specimens were notched with a U-shaped, 1/8-in. radius cutter. Table 2 shows the results of this investigation. The extrapolation required to obtain the bend angle for 400° F preheat was small and there is probably no error involved. These experiments, involving slightly larger specimens than were used by Kennedy, indicate that 400° F preheat is just as effective as 1100° F stress-relief heat treatment in improving the performance of weldments. An interesting sidelight reported by the investigator is that the preheated specimens performed as well as the stress-relieved specimens although thay had a much higher hydrogen content.

Table 2—Results of Bend Tests (Flanigan)

Fabrication	*Bend angle, deg*
375° F preheat	23
400° F preheat (by extrapolation)	27
1150° F	28

Also in 1947 this writer and his associates[4] reported the results of tests made on very large hatch corner type specimens. In these tests specimens were tested in the as-welded, 400° F preheat, and 1000° F stress-relieved conditions. When using preheat the material within 6 in. of the welds was maintained at 400° F. The stress-relieved specimen was held at 1000° F for 8 hr and then cooled in the furnace. All of the specimens were tested at 70° F. Type E6010 electrode was used in these specimens. The results are shown in Table 3. In these large specimens 400° F preheat produced results superior to those obtained with 1000° F stress-relief treatment. It was also noted by the investigators that the preheated specimens were more ductile than the one which was stress relieved.

Table 3—Results of Hatch Corner Tests (DeGarmo, *et al.*)

Fabrication	*Breaking stress, psi*
As-welded	20,750
400° F preheat	32,700
1000° F stress relief	30,000

Daniels, Gardner and Rood,[5] in 1948, reported on both tensile and impact tests made with low-carbon steel specimens welded with Type E6010 electrodes. While these tests do not give a comparison with high-temperature stress relief, they do show once more, as indicated in Table 4, the effectiveness of 400° F preheat in improving ductility and transition temperature characteristics without adversely affecting the tensile properties.

Table 4—Results of Tensile and Impact Tests (Daniels, Gardner and Rood)

Welding temp., ° F	*Yield strength, psi*	*Ultimate strength, psi*	*Elongation %*	*Transition Temp.,* ° F*
72	51,400	71,400	22.5	+40
400	51,200	71,900	27.5	+25

* Mid-point of transition curve.

In 1948 Davis, Troxell, Parker and Boodberg[6] conducted extensive bend tests on mild-steel specimens which were 10 in. square and 3/4 in. thick, with a weld bead deposited on one face along a centerline. These tests were made at −40° F. The results of tests made on specimens using Type E6010 and Unionmelt electrodes are shown in Table 5. Here again the beneficial effects of preheat are apparent. In the case of the Unionmelt welds the results of the preheated

Table 5—Results of Bend Tests (Davis, *et al.*)

Condition	*Electrode*	*Bend angle, deg*
As-welded, 75° F	E6010	22
400° F preheat	E6010	72
100° F preheat, 1100° F postheat	E6010	93
As-welded, 75° F	Unionmelt	42
400° F preheat	Unionmelt	82
100° F preheat, 1100° F postheat	Unionmelt	83

and stress-relieved specimens were almost identical. The stress-relieved E6010 specimens were somewhat better than those welded with 400° F preheat. However, it should be noted that the stress relieved specimens also had 100° F preheat and tests by these investigators showed a significant improvement in performance when preheat was increased from 75 to 100° F.

Earlier this year this writer reported the results of a series of bend tests[7] made on low-carbon steel specimens 30 x 36 x $^3/_4$ in. with a full butt weld along the 30-in. centerline. In these tests, made at −80° F, a direct comparison was obtained between specimens made with 400° F preheat and 1200° F stress relief. The results, shown in Fig. 1, show that 400° F preheat and 1200° F stress relief were equally effective in improving the performance of these rather good sized weldments.

Another impressive series of tests has been carried out recently by Prof. W. J. Krefeld and his associates at Columbia University. These are impact tests on welded beams 14 ft. long. At this date the tests are not complete and the results have not yet been published.

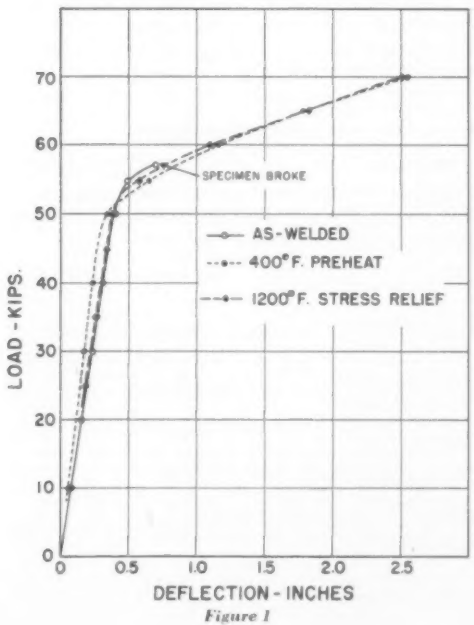

Figure 1

Table 6—Results of Impact Tests on Large Beams (Krefeld)

Type steel	*Fabrication*	*Transition temperature, ° F.*
Fully killed	As-welded	−29
Fully killed	350–400° F preheat	−58
Fully killed	Stress relieved, 1150° F	−45
Semikilled	As-welded	−5
Semikilled	350–400° F preheat	−17
Semikilled	Stress relieved, 1150° F	−10

However, Table 6 gives the results of a portion of these tests relating to the effects of preheating and stress relieving. Here again the effectiveness of 400° F preheat was found to be as good as, or better then, 1150° F stress-relief heat treatment.

The fact that in each of the cases cited wherein large specimens and full welds were involved, preheating at 400° F was found to be as good as stress relieving, but that in certain instances when the specimens were small and single weld beads were used (as by Kennedy and by Davis and his associates) preheating was not quite as effective as stress relieving may have some significance. Certainly the larger specimens and full welds more nearly approximate actual weldments. While the use of a single weld bead on a plate might approximate the condition where an attachment is made with a single bead and thus lead to the conclusion that in such cases preheating is not quite as effective as stress relieving, it appears more likely that the differences found were due to size effects.

EFFECT OF PREHEATING AND STRESS RELIEVING ON FATIGUE STRENGTH

The evidence presented to this point is substantial in indicating that 400° F preheat is as effective as 1100° F stress-relief heat treatment in improving the performance of low-carbon steel weldments, fabricated with Type E6010 electrode, when subjected to static or impact loading. Two other conditions are important: namely, fatigue loading and stress corrosion. In order to get some indication of the relative effectiveness of these two fabrication procedures under fatigue conditions, the author has recently completed what might be termed an exploratory set of tests. These tests were not exhaustive in nature since no equipment was available to permit testing on specimens of the size which it is believed should be used if a completely satisfactory answer is to be obtained. It is believed that a truly satisfactory specimen would be at least 12 in. wide and at least 2 ft long so as to permit the full effects of preheating, residual stresses, etc., to be obtained. Since such specimens could not be used, the tests conducted were rather limited, having as their objective the obtaining of some indication of the possible relative effectiveness of preheating and stress relieving, and the encouraging of some other investigators, who have proper equipment available, to undertake similar tests on larger specimens.

The specimens consisted of two pieces of steel 2 x 24 x $^1/_4$ in. joined along their 24-in. edges by a full butt weld

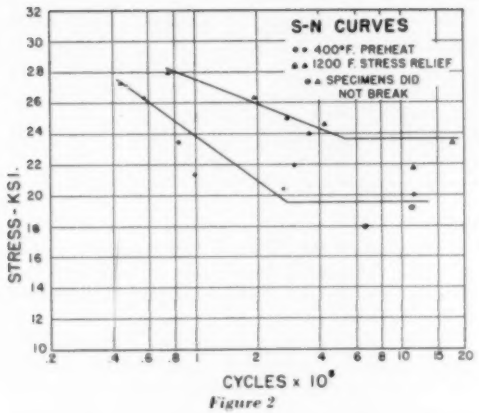

Figure 2

made with E6010 electrode so as to form a specimen 4 x 24 x ¾ in. The material was a plain-carbon, semi-killed steel having 0.15% carbon. The weld beads were machined smooth, even with the plate, and the specimens then tested in a magnetic type of fatigue testing machine in which the specimens vibrated at their natural frequency with predetermined deflections. The results are shown in Fig. 2. It will be noted that the endurance strength of the specimens stress relieved at 1200° F was about 4000 psi greater than that of those welded with 400° F preheat. From these results it appears that 400° F preheat may not be quite as beneficial as stress-relief heat treatment in improving the endurance strength of weldments. However, this conclusion may not be correct for several reasons. The specimens used in this test were quite small. As was mentioned previously, in the case of bend tests when small specimens were used preheat did not always appear to be quite as effective as stress relief. Yet when large bend-test specimens were used, and also in the case of the hatch corners and large beams, preheating was just as effective as stress relieving. The same may also be true for fatigue specimens. Also the weld beads were machined from the specimens used in these fatigue tests. There is considerable reason for believing that the results would be somewhat different if the weld beads remained on the specimens as would be the case in ordinary weldments. Thus it is most desirable for fatigue tests to be conducted on large specimens with the weld beads intact.

STRESS CORROSION

Where conditions conducive to stress corrosion exist there is considerable room for doubt as to whether preheating would be a suitable substitute for stress relieving. Since preheating does little to reduce residual stresses one quite naturally could conclude that it would not improve stress corrosion resistance. However, although such reasoning may be correct, it probably is advisable to have an open mind on this this subject until sound evidence has been obtained. It should be recalled that at one time it was quite widely believed that the benefits received from 1200° F stress-relief heat treatment were due to the removal of stresses. Today we know that this is not true. Similarly the improvement in stress corrosion resistance brought about by stress-relief heat treatment may not be due entirely to the removal of stresses. Certainly some research to determine the effects of preheating on stress corrosion resistance is urgently needed.

CONCLUSION

The results of the researches cited here indicate quite conclusively that 400° F preheat is a satisfactory substitute for 1100–1200° F stress-relief heat treatment on mild-steel weldments, fabricated with Type E6010 electrode, when such weldments are to be subjected to static or impact loads, providing fatigue conditions do not prevail. This evidence is substantial enough to justify modification of the various welding codes to permit this substitution for such conditions.

Fatigue tests on large size specimens should be conducted as soon as possible to determine more completely the relative effectiveness of preheating and stress relieving in improving the endurance strength of weldments, with the view of enabling modifications of welding codes where fatigue is a factor. In addition the effectiveness of preheating as a means of improving stress corrosion resistance should be investigated with the objective that possible code revision might result.

If suitable sound modifications of the welding codes can be made on the basis of the studies cited and proposed herein, the use of welding can be extended appreciably to the benefit of all concerned.

ACKNOWLEDGMENT

The writer wishes to express his indebtedness to Charles H. Lockrem for his assistance in conducting the fatigue tests, and to Prof. W. J. Krefeld for permitting the use of some of his unpublished data.

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The Strength and Ductility of Welds in Aluminum Alloy Plate

A comprehensive presentation of tensile-bend test data of butt and fillet welds of aluminum alloys

by F. G. Nelson, Jr., and F. M. Howell

Abstract

This paper presents data accumulated over a period of several years on the strength and ductility of welds made in aluminum alloys by the argon-shielded tungsten-arc method and the semiautomatic and automatic argon-shielded consumable-electrode methods. The data consist of tensile strength and free-bend elongation of butt welds and shear strength of longitudinal and transverse fillet welds. They represent some 1100 tensile tests, 500 free-bend tests and 200 longitudinal and transverse shear tests. The aluminum alloys are those most commonly used by commercial fabricators, including five nonheat-treatable alloys (2S, 3S, 4S, 52S and XA54S), and the heat-treatable alloy 61S. The filler wires used were generally 43S alloy or parent metal.

IN THE past ten years there have been developed many new methods of welding most of which are variations of the basic metal-arc process. Through the use of three of these methods—the argon-shielded tungsten-arc and the automatic and semiautomatic argon-shielded consumable-electrode methods—it has been possible to butt weld aluminum alloy plate so that the weld will develop tensile strengths equaling or approaching the strength of the parent metal. In addition there has been a marked increase in the ductility of welds in the higher strength alloys. These new methods also tend to promote the increased use of fabricated parts, such as "T" sections, where it is often economical to fabricate such a section by welding rather than to make tools for an extruded or rolled shape.

The object of this paper is to present information on the tensile strength and ductility of welds in several aluminum alloys used in welded construction. Data are also presented on the shear strength of fillet welds of the same alloys. The alloys were the Alcoa nonheat-treatable alloys 2S, 3S, 4S, 52S and XA54S, and heat-treatable alloy 61S. Their nominal compositions are shown in Table 1.

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Table 1—Nominal Compositions of Wrought Aluminum Alloys

Alcoa alloy	Element, % Al	Cu	Si	Mn	Mg	Cr
2S	99.0 min	...	...	...	...	...
3S	Remainder	...	...	1.2	...	...
4S	Remainder	...	...	1.2	1.0	...
52S	Remainder	...	...	...	2.5	0.25
XA54S*	Remainder	...	...	...	3.5	0.25
61S	Remainder	0.25	0.6	...	1.0	0.25

* Experimental alloy.

WELDING PROCEDURE AND TEST SPECIMENS

The argon-shielded tungsten-arc method and the automatic and semiautomatic argon-shielded consumable-electrode methods of welding were used, although not all three methods were employed for each alloy.

As it would be virtually impossible to present the welding procedure followed in preparing each of the plates in this investigation, the procedures will be discussed in a general manner. Standard commercial equipment available on market was used. All butt-welded plates welded by the argon-shielded tungsten-arc method were given a preheat consistent with the alloy, generally around 400° F; plates welded by either of the other two methods received a somewhat lower preheat. Some of the welded test plates were back chipped or welded using backing strips while others were not. Practically all of the welds were made in downhand position. The number of passes required to complete the weld varied with the thickness and established procedures. The argon gas flow varied from 40 to 80 lpm.

All butt-welded plates were radiographed prior to the preparation of specimens and were generally free of deleterious discontinuities.

Alcoa aluminum alloys 2S and 3S were welded in three tempers: −0, −F and −H12, while the other nonheat-treatable alloys 4S, 52S and XA54S* were usually welded in the −H112 or −F tempers. The only heat-treatable alloy used, 61S-T6, was investigated both with and without a subsequent thermal treatment. Whenever it received a subsequent thermal treatment, the treatment was performed following commercial procedures.

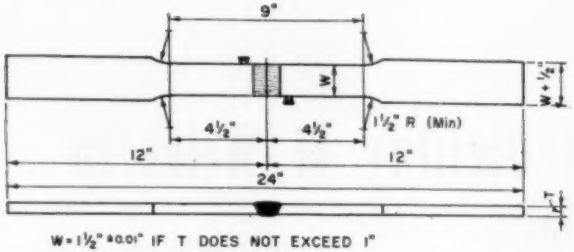
The thicknesses of plate generally ranged from 1/4 to 1 in., although for some alloys, plate as thin as 1/8 in. and as thick as 2 in. was tested.

The filler wires used were 2S, 43S (5% Si) and parent metal (filler wire of the same composition as the plate). The diameter of filler wire used with the automatic and semiautomatic methods was 1/8 in. or less, while with the tungsten-arc method the diameter was 1/4 in.

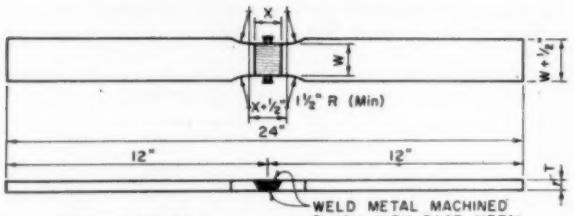
For the determinations of tensile strength and ductility, butt-welded panels 24 to 36 in. wide and 18 to 48 in. long were prepared, with the weld at the center of the width. The tensile tests were made using both reduced-section specimens and full-section specimens, while the ductility of the weld was determined from free face bend tests. The specimens are shown in Fig. 1. The reduced-section tensile specimens and the free-face bend specimens were prepared in accordance with the ASME Boiler Construction Code.†

* XA54S although not a new alloy is still in the experimental or "X" status.

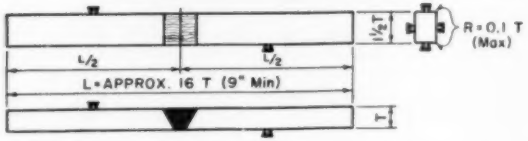
† Standard Qualification for Welding Procedure and Welding Operator, Section IX, ASME Boiler Construction Code, 1949 edition.



FULL-SECTION TENSILE SPECIMEN



REDUCED-SECTION TENSILE SPECIMEN



FREE FACE BEND SPECIMEN

Fig. 1 Specimens from butt- (groove) welded plate

The reduced-section tensile specimen is designed primarily to force the fracture into the weld; therefore, the weld bead is removed and the reduced section is short. The full-section tensile specimen is one in which the weld bead is not removed and the reduced section of the specimen is 9 in. long thus allowing failure to occur either at or adjacent to the weld, whichever location is weaker.

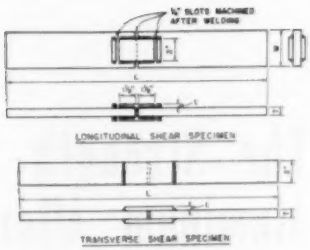


FIG. 2 - FILLET WELD SPECIMENS

Fig. 2 Fillet weld specimens

The shearing strengths of fillet welds were determined from longitudinal and transverse shear specimens as shown in Fig. 2. These specimens are in general conformity to those prescribed by Section IX of the Boiler Code. Various thicknesses of base plates and cover plates were used, the thickness generally being based on the nominal size of the fillet, where the nominal fillet size ranged from 1/4 in. for single-pass fillets to 3/4 in. for multiple-pass fillets. Usually the base plates and cover plates were in the —F temper, although in some instances material that had received some strain hardening was used. Shear test specimens prepared using 61S-T6 plate were not given any subsequent thermal treatment.

TEST PROCEDURE

The tensile and shear tests were made either in a Baldwin universal testing machine of 50,000 lb capacity or in an Amsler universal testing machine of 100,000 lb capacity. Both testing machines meet the ASTM and government requirements for accuracy.

The free-face bend tests were conducted in the manner prescribed by the Boiler Code.

In the tests of the fillet welds the shear strengths were recorded in total pounds,

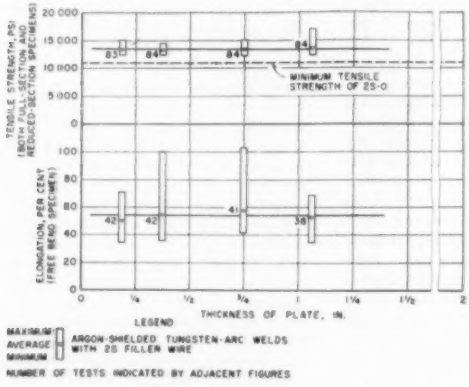

TENSILE STRENGTH, PSI (BOTH FULL-SECTION AND REDUCED-SECTION SPECIMENS)
ELONGATION, PER CENT (FREE BEND SPECIMEN)
MINIMUM TENSILE STRENGTH OF 2S-O
THICKNESS OF PLATE, IN.
LEGEND
MAXIMUM
AVERAGE
MINIMUM
ARGON-SHIELDED TUNGSTEN-ARC WELDS WITH 2S FILLER WIRE
NUMBER OF TESTS INDICATED BY ADJACENT FIGURES

Fig. 3 Strength and ductility of butt (groove) welds in 2S plate

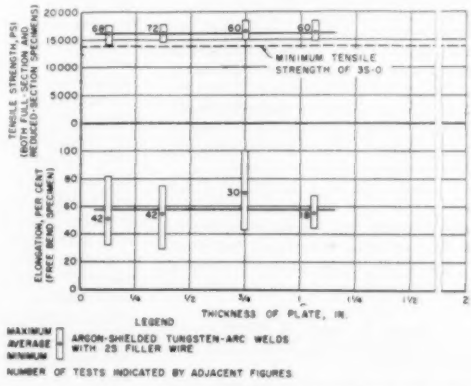

TENSILE STRENGTH, PSI (BOTH FULL-SECTION AND REDUCED-SECTION SPECIMENS)
ELONGATION, PER CENT (FREE BEND SPECIMEN)
MINIMUM TENSILE STRENGTH OF 3S-O
THICKNESS OF PLATE, IN.
LEGEND
MAXIMUM
AVERAGE
MINIMUM
ARGON-SHIELDED TUNGSTEN-ARC WELDS WITH 2S FILLER WIRE
NUMBER OF TESTS INDICATED BY ADJACENT FIGURES

Fig. 4 Strength and ductility of butt (groove) welds in 3S plate

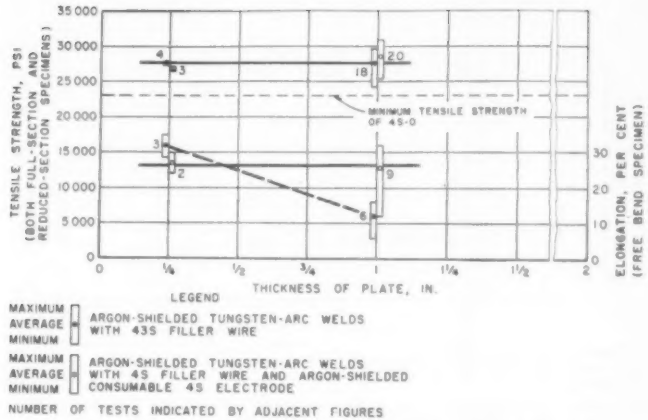

TENSILE STRENGTH, PSI (BOTH FULL-SECTION AND REDUCED-SECTION SPECIMENS)
ELONGATION, PER CENT (FREE BEND SPECIMEN)
MINIMUM TENSILE STRENGTH OF 4S-O
THICKNESS OF PLATE, IN.
LEGEND
MAXIMUM
AVERAGE
MINIMUM
ARGON-SHIELDED TUNGSTEN-ARC WELDS WITH 43S FILLER WIRE
ARGON-SHIELDED TUNGSTEN-ARC WELDS WITH 4S FILLER WIRE AND ARGON-SHIELDED CONSUMABLE 4S ELECTRODE
NUMBER OF TESTS INDICATED BY ADJACENT FIGURES

Fig. 5 Strength and ductility of butt (groove) welds in 4S plate

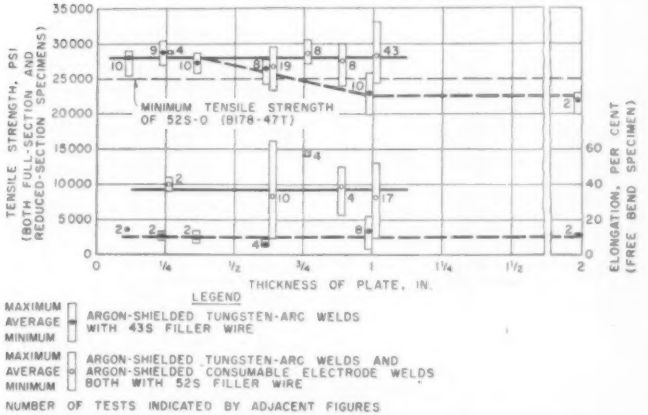

TENSILE STRENGTH, PSI (BOTH FULL-SECTION AND REDUCED-SECTION SPECIMENS)
ELONGATION, PER CENT (FREE BEND SPECIMEN)
MINIMUM TENSILE STRENGTH OF 52S-O (B178-47T)
THICKNESS OF PLATE, IN.
LEGEND
MAXIMUM
AVERAGE
MINIMUM
ARGON-SHIELDED TUNGSTEN-ARC WELDS WITH 43S FILLER WIRE
ARGON-SHIELDED TUNGSTEN-ARC WELDS AND ARGON-SHIELDED CONSUMABLE ELECTRODE WELDS BOTH WITH 52S FILLER WIRE
NUMBER OF TESTS INDICATED BY ADJACENT FIGURES

Fig. 6 Strength and ductility of butt (groove) welds in 52S plate

Table 2—Summary of Strength and Ductility of Butt-Welded Plate

Alloy		Plate thickness, in.		Specified minimum tensile strength of annealed plate, psi	Average tensile strength across weld, psi	Average free-bend elongation, %
Plate	Filler wire	Min	Max			
2S	2S	3/16	1 1/16	11,000	13,500	55
3S	2S	3/16	1 1/16	14,000	16,000	58
4S	4S	1/4	1	23,000	28,000	26
	43S	1/4	1/4	23,000	28,000	32
	43S	1	1	23,000	28,000	12
52S	52S	1/4	1	25,000	28,000	38
	43S	1/8	3/8	25,000	28,000	10
	43S	1	2	25,000	22,500	10
XA54S	XA54S	1/4	1	30,000	33,000	39
	43S	1/4	1/4	30,000	29,000	8
	43S	1	1	30,000	25,000	8
61S-T6*	43S	1/4	3/8	42,000‡	30,000	15
	43S	1/2	1 1/2	42,000	26,000	15
61S-T6†	43S	1/4	1 1/2	42,000	43,000	10

* Without any subsequent thermal treatment.
† Heat treated and aged after welding.
‡ Minimum tensile strength for 61S-T6 plate.

in pounds per inch of length of fractured weld, and in unit strengths in pounds per square inch based on the throat depths, the throat depth being computed from the measured hypotenuse of the weld. Previous tests of this kind indicated that in the determinations of unit shearing strength it is not satisfactory to use the nominal size of the fillet weld.

RESULTS AND DISCUSSION

The tensile strengths and elongations are plotted against thickness of plate in Figs. 3 to 9 for the different welded alloys and the different kinds of filler wire. The number of each kind of test of each thickness, the average value and the range of values are shown. The effects of other variables, such as method and position of welding, generally were quite small, and therefore are not considered separately.

The average tensile strength of 2S plate welded with 2S filler was about 13,500 psi, and the average free-bend elongation about 55%, as shown in Fig. 3. These values are the same regardless of thickness. The lowest tensile strength in any individual test was 12,300 psi, and the lowest elongation was 34%. It is evident that tensile strengths greater than the guaranteed minimum tensile strength of 2S-O, 11,000 psi,* can be obtained consistently with good ductility regardless of the thickness of the plate.

For 3S plate welded with 2S filler wire, the average tensile strength was about 16,000 psi and the average free-bend elongation was about 58%, as shown in Fig. 4. As in the case of 2S plate, these values are about the same for all thicknesses tested. The tensile strengths were quite consistent, the lowest individual value still being above the minimum tensile strength of 3S-O (14,000 psi).*

The lowest elongation was about 30%. As in the case of 2S alloy, butt welds in 3S can be made that will consistently have tensile strengths exceeding the minimum value, 14,000 psi,* required for the annealed temper, 3S-O, and the welds will have good ductility. The tensile strength and ductility obtained meet the requirements for strength and ductility in Revised Case 994 of the Boiler Code Committee.†

In the tests of welded 4S plate, two compositions of filler wire, 4S and 43S, were used. As shown in Fig. 5, the average tensile strengths were the same, 28,000 psi, for either kind of filler wire and all thicknesses of plate, and even the lowest individual value exceeded the guaranteed minimum tensile strength of 23,000 psi for 4S-O.*The ductility differed however, depending upon the kind of filler wire. For 4S filler wire it averaged

* ASTM Tentative Specifications for Aluminum and Aluminum Alloy Sheet and Plate for Use in Pressure Vessels (B178-51T), 1950 Supplement to Book of ASTM Standards.
† Mechanical Engineering, **71**, No. 2, 178 (February 1949).

about 26% regardless of thickness. For 43S filler wire, the ductility of welds in $^1/_8$-in. plate was slightly better than for 4S wire; for welds in 1-in. plate, the ductility, 12%, was somewhat lower when 43S filler wire was used. The strength requirements of Case 1114 of the Boiler Code Committee covering 4S alloy were easily met. In a few individual tests, however, the welds did not meet the minimum ductility requirements of the Case, which are 8% for 43S filler wire and 15% for 2S filler wire. This shows that the ductility requirements set by Case 1114 for welds made with 43S filler wire are somewhat higher than can be met consistently.

In the tests of welded 52S alloy plate, there were two compositions of filler wire, 52S and 43S, and the results are shown in Fig. 6. The tensile strength of the plates welded using 52S filler metal are relatively consistent, averaging about 28,000 psi for all thicknesses tested. For plate welded with 43S wire, the tensile strength was less for the larger thicknesses. The average tensile strengths of welds in plate of all thicknesses welded with 52S wire, and in plate less than $^3/_4$ in. thick welded with 43S wire, exceeded the minimum value of 25,000 psi required for 52S-O.* For plate 1 to 2 in. thick welded with 43S wire, however, the tensile strength averaged about 2500 psi below this value. The free-bend elongation for welds made with 52S wire averaged 38%, and for welds made with 43S wire, 10%, regardless of thickness.

The strength and ductility of welds in XA54S alloy plate made with 43S and with XA54S filler wires are shown in Fig. 7. All values for XA54S plate welded using XA54S filler wire are above the tentative minimum tensile strength of 30,000 psi for XA54S-O, averaging about 33,000 psi. When XA54S plate was welded using 43S filler wire, however, the tensile strength was below the minimum for XA54S-O, the difference becoming larger with increase in thickness. The average elongation, as shown in Fig. 7, of welds made using XA54S filler wire was about 39% while for 43S welds the average elongation was only about 8%.

The strength and ductility of welds in 61S-T6 plate that received no subsequent thermal treatment are shown in Fig. 8. All welds were made with 43S filler wire. The heat created by the welding process removed much of the beneficial effects of the heat treatment, and the strengths and ductilities of the welds showed more variation than those of welds in nonheat-treatable alloys. The average strength decreased from 33,000 to 26,000 psi, as the plate thickness was increased to $^1/_2$ in. For larger thicknesses the aver-

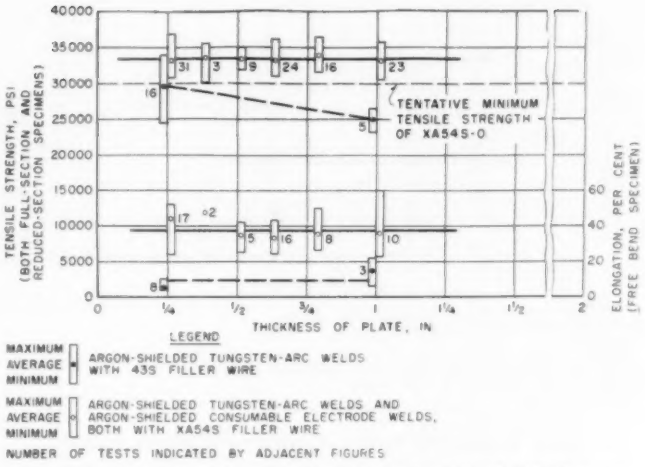

TENSILE STRENGTH, PSI (BOTH FULL-SECTION AND REDUCED-SECTION SPECIMENS)
ELONGATION, PER CENT (FREE BEND SPECIMEN)
THICKNESS OF PLATE, IN.
TENTATIVE MINIMUM TENSILE STRENGTH OF XA54S-O
LEGEND
MAXIMUM
AVERAGE
MINIMUM
ARGON-SHIELDED TUNGSTEN-ARC WELDS WITH 43S FILLER WIRE
ARGON-SHIELDED TUNGSTEN-ARC WELDS AND ARGON-SHIELDED CONSUMABLE ELECTRODE WELDS, BOTH WITH XA54S FILLER WIRE
NUMBER OF TESTS INDICATED BY ADJACENT FIGURES

Fig. 7 Strength and ductility of butt (groove) welds in X A54S plate

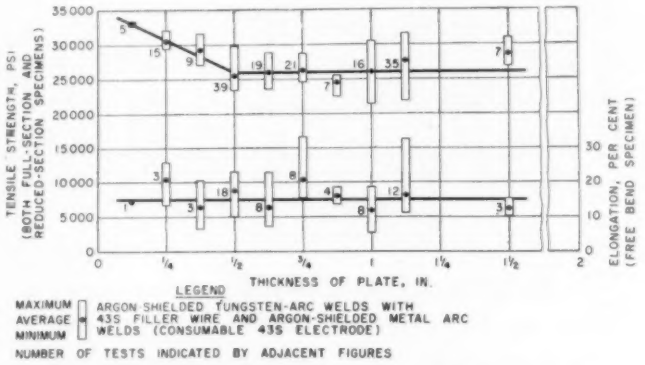

TENSILE STRENGTH, PSI (BOTH FULL-SECTION AND REDUCED-SECTION SPECIMENS)
ELONGATION, PER CENT (FREE BEND SPECIMEN)
THICKNESS OF PLATE, IN.
LEGEND
MAXIMUM
AVERAGE
MINIMUM
ARGON-SHIELDED TUNGSTEN-ARC WELDS WITH 43S FILLER WIRE AND ARGON-SHIELDED METAL ARC WELDS (CONSUMABLE 43S ELECTRODE)
NUMBER OF TESTS INDICATED BY ADJACENT FIGURES

Fig. 8 Strength and ductility of butt (groove) welds in 61S-T6 plate without subsequent thermal treatment

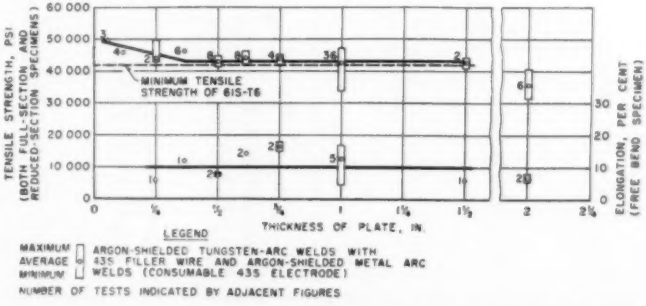

TENSILE STRENGTH, PSI (BOTH FULL-SECTION AND REDUCED-SECTION SPECIMENS)
ELONGATION, PER CENT (FREE BEND SPECIMEN)
THICKNESS OF PLATE, IN.
MINIMUM TENSILE STRENGTH OF 61S-T6
LEGEND
MAXIMUM
AVERAGE
MINIMUM
ARGON-SHIELDED TUNGSTEN-ARC WELDS WITH 43S FILLER WIRE AND ARGON-SHIELDED METAL ARC WELDS (CONSUMABLE 43S ELECTRODE)
NUMBER OF TESTS INDICATED BY ADJACENT FIGURES

Fig. 9 Strength and ductility of butt (groove) welds in 61S-T6 plate heat treated and aged after welding

* ASTM Tentative Specifications for Aluminum and Aluminum Alloy Sheet and Plate for Use in Pressure Vessels (B178-51T), 1950 Supplement to Book of ASTM Standards.

age strength remained constant at 26,000 psi. The average free-face bend elongation was about 15%, regardless of thickness. The strengths of the welded joints were from 60 to 75% of the minimum required tensile strength of 42,000 psi for 61S-T6 plate.*

The strength and ductility of 61S-T6 plate welded with 43S filler wire and then reheat treated and artificially aged are shown in Fig. 9. The tensile strengths were substantially higher when the welded plate was heat treated after welding, the average value of 43,000 psi for thicknesses from 3/8 to 1 1/2 in. exceeding the minimum tensile strength of 61S-T6, 42,000 psi.* The elongations, however, were slightly lower, averaging about 10%. The data are sufficient to establish only an approximate average value.

The average tensile strengths and ductilities of butt welds in the various alloys are summarized in Table 2. For 4S, 52S, and XA54S alloys welded with parent metal, the welded XA54S had the highest tensile strength. The ductilities of XA54S and 52S were about equal, and were higher than for 4S. When XA54S and 52S alloys were welded with 43S wire, the strengths and ductilities generally were lower than when parent metal was used. The highest strengths were those of the 61S-T6 welded with 43S filler wire and reheat treated after welding.

The results of the longitudinal and transverse shear tests of fillet welds are shown in Tables 3 and 4. The total strengths of the fillet weld specimens, and their strengths in pounds per inch, varied considerably with the actual size of the fillet. In the longitudinal direction these strengths ranged from about 3200 to 7000 lb per inch, and in the transverse direction from about 3400 to 10,800 lb per inch. Based on the actual fillet size, the unit strengths in the longitudinal direction ranged from 11,200 to 18,300 psi, and in the transverse direction from 12,700 to 24,000 psi. In general, it appears that in the longitudinal direction higher unit shear strengths were obtained when 43S filler wire was used, but that in the transverse direction the higher strengths were obtained with parent metal filler wire.

SUMMARY AND CONCLUSIONS

A total of 1100 tensile and 500 free-bend tests of butt welds, and 200 shear tests of fillet welds, were made in plate of six aluminum alloys in thicknesses from 1/8 to 2 in. The filler metal, generally was either parent metal or 43S.

The average tensile strengths of all of the welds in 2S, 3S and 4S plate, and of the welds in 52S and XA54S made with parent metal, exceeded the required minimum strengths of the annealed tem-

* ASTM Tentative Specifications for Aluminum and Aluminum Alloy Sheet and Plate for Use in Pressure Vessels (B178–51T), 1950 Supplement to Book of ASTM Standards.

Table 3—Longitudinal Shear Strength of Fillet Welds

Alloy		Thickness, in.		Average fillet size,	Shear strength		
Plate	Filler wire	Base plate	Cover plate	in.	lb	lb/in.	psi
2S	2S	3/4	1/2	0.46	21,800	3640	11,200
	2S	1 1/4	1	0.58	32,700	5450	13,400
3S	2S	3/4	1/2	0.45	21,600	3590	11,400
	2S	1 1/4	1	0.60	33,200	5520	12,500
	43S	3/4	1/2	0.41	19,400	3240	11,200
	43S	1	3/4	0.44	25,300	4210	13,500
4S	43S	3/4	1/2	0.36	23,200	3860	15,000
	43S	1	3/4	0.43	29,700	4960	16,300
52S	43S	5/8	5/8	0.41	24,400	4060	16,400
	43S	7/8	7/8	0.51	29,600	4940	14,500
	43S	7/8	7/8	0.75	36,900	6150	11,600
	52S	5/8	5/8	0.49	29,400	4910	14,100
	52S	3/4	1/2	0.44	20,000	3300	10,600
	52S	1	3/4	0.62	31,700	5300	12,100
	52S	7/8	7/8	0.54	34,800	5790	15,300
	52S	7/8	7/8	0.75	41,500	6920	13,000
XA54S	43S	3/4	1/2	0.35	24,400	4060	16,400
	43S	1	3/4	0.42	32,600	5440	18,300
	XA54S	3/4	1/2	0.45	28,300	4700	14,700
	XA54S	1	3/4	0.71	41,700	7000	14,000
61S-T6*	43S	3/4	1/2	0.36	28,100	4680	18,200
	43S	1	3/4	0.42	30,800	5140	17,400

* Without any subsequent thermal treatment.

Table 4—Transverse Shear Strengths of Fillet Welds

Alloy		Thickness, in.		Average fillet size,	Shear strength		
Plate	Filler wire	Base plate	Cover plate	in.	lb	lb./in.	psi
2S	2S	3/4	3/8	0.41	18,400	3,670	12,700
	2S	1 1/4	3/4	0.54	29,000	5,800	15,300
3S	2S	3/4	3/8	0.42	20,200	4,020	13,800
	2S	1 1/4	3/4	0.53	28,000	5,590	15,000
	43S	3/4	3/8	0.39	17,200	3,440	12,700
	43S	1	1/2	0.42	21,000	5,200	17,600
4S	43S	3/4	3/8	0.35	18,700	3,740	14,900
	43S	1	1/2	0.42	27,900	5,480	18,600
52S	43S	5/8	5/8	0.48	29,200	5,840	17,000
	43S	5/8	5/8	0.58	51,300	6,410	15,800
	43S	7/8	7/8	0.76	89,200	9,910	18,400
	52S	5/8	5/8	0.48	40,200	8,040	24,000
	52S	3/4	3/8	0.39	27,800	5,570	20,200
	52S	1	1/2	0.58	43,000	8,600	21,000
	52S	5/8	5/8	0.56	66,900	8,360	20,900
	52S	7/8	7/8	0.74	97,000	10,800	20,600
XA54S	43S	3/4	3/8	0.51	24,500	4,900	13,600
	43S	1	1/2	0.61	29,600	5,920	13,800
	XA54S	3/4	3/8	0.46	34,200	6,830	21,200
	XA54S	1	1/2	0.60	41,800	8,360	19,800
61S-T6*	43S	3/4	3/8	0.35	29,300	5,860	23,400
	43S	1	1/2	0.42	30,800	6,160	20,800

* Without any subsequent thermal treatment.

Table 5—Summary of Shear Strengths of Fillet Welds

Alloy		Average shear strength, psi	
Plate	Filler wire	Longitudinal	Transverse
2S	2S	12,300	14,000
3S	2S	12,000	14,400
	43S	12,400	15,200
4S	43S	15,600	16,800
52S	52S	13,000	21,300
	43S	14,200	17,100
XA54S	XA54S	14,400	20,500
	43S	17,400	13,700
61S-T6*	43S	17,800	22,100

* Without any subsequent thermal treatment.

pers of the respective alloys, as shown in Table 2. The strengths of welds in the greater thicknesses of 52S and in all thicknesses of XA54S, when welded with 43S filler metal, did not meet these requirements. The average free-bend elongation of welds made with parent metal ranged from 26 to 58% for these same alloys; the elongations generally were lower when the welds were made with 43S

The strengths of welds in 61S-T6 plate made with 43S filler wire, and with no subsequent thermal treatment, were about 60 to 75% of the minimum required for 61S-T6 plate. When the plate was reheat treated and aged after welding, the strength was increased considerably, and then exceeded the minimum for 61S-T6. The ductility, however, was decreased.

The average unit shear strengths of fillet welds, as shown in Table 5, ranged from about 12,000 to 22,000 psi. These shear strengths averaged about 20% higher in the transverse than in the longitudinal direction.

Stresses in Circular-Patch Weld-Test Specimens

An investigation of the residual stresses in specimens of various plate and patch sizes

by Alan V. Levy and Harry E. Kennedy

Introduction

MANY tests, ranging from simple tension tests of butt-welded plate to much more complicated notch-bend tests, have been used to qualify welds and welding procedures. A major shortcoming of many of these tests is that the complicated system of combined stresses which frequently exist in a service welding application does not exist in the test specimens.

The circular-patch type of weld-test specimen promises to supply the restraint needed to produce combined stresses similar to those found in service. This test consists essentially of cutting a circular patch from the center of a square plate and welding it back into its original position. Even though the condition of maximum possible restraint is attained by this procedure, this test has received but limited use. The U. S Navy employs a patch test to qualify welding electrodes and fluxes[1,2]; recently, several companies have begun to use such tests in their welding research programs. However, very little work has been published concerning the analysis of circular-patch weld tests.[8,9] It is known that the smaller the ratio of patch size to plate size, the greater is the restraint. Therefore, all specifications to date simply indicate the size patch for a given size plate that should not result in cracking. It was felt that a comprehensive study of the stresses of a circular-patch weld test would be of value to the present and future users of this test.

This investigation was concerned with a study of the residual stresses in specimens of various plate sizes and patch sizes. Most uses of the test to date have been restricted to specimens which are too large to be handled by one person. The use of smaller specimens is preferred, providing they can duplicate the restraint provided by the larger specimens. In this work, the patch size was varied from 3 to 8 in. in diameter. The plates employed varied from 9 to 18 in. sq. The patches were cut from the plate and scarfed to A W S standards by flame cutting. Unionmelt welds backed up with hand welds were used to join the patch to the plate. The magnitude of the residual stresses induced in the plates by the welding were later determined with SR-4 strain gages glued to the plate. The stresses were relieved by cutting the gage sections out of the plate with a saw.

The specimens were Unionmelt welded to avoid the variables introduced by hand welding. A hand backup weld was used before Unionmelt welding. The hand weld provided approximately 40% of the total weld metal deposited. A cross section of a typical weld (Fig. 1) shows that the effect of the hand weld was almost completely removed by the heat and depth of penetration of the machine weld.

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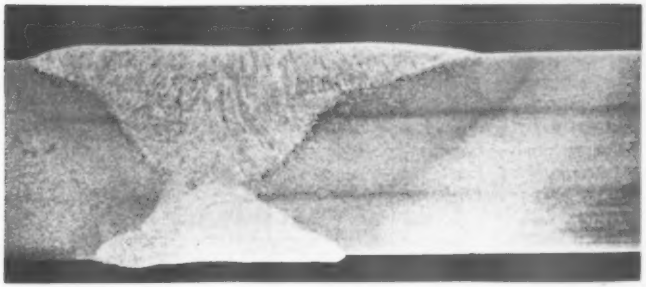

Fig. 1 Weld cross section

Procedure

The specimens used were flame cut from a 22- by 7-ft by 1-in. hot-rolled mild-steel plate. The chemical composition of this steel was: 0.24% carbon, 0.50% manganese, 0.07% silicon, 0.05% chromium, 0.08% nickel, 0.07% copper, 0.04% aluminum, 0.05% sulfur and 0.045% phosphorus. The circular patches were flame-cut by rotating the specimens under a stationary torch. A variable speed turntable was constructed to rotate the specimen for the flame cutting and also for the subsequent welding. The specimens were scarfed according to standard procedure for 1-in. plate. For the hand welding, the plates were preheated to 300° F and tack welded with E6010 electrodes. The backup weld was subsequently completed with E6020 rod. A single hand pass was laid in the top weld groove prior to completing the final weld by the Unionmelt process. Number 36 wire and No. 90 flux were used for the welding. The welding speed was 10 ipm. Operating conditions were: current = 850 amp; open-circuit voltage = 36 v; closed circuit = 32 v; reverse polarity was used.

SR-4 resistance wire strain gages were used to determine residual stresses. The plates were ground flat on both sides along a radius perpendicular to the rolling direction. The gages were mounted to the plate, as shown in Fig. 2.

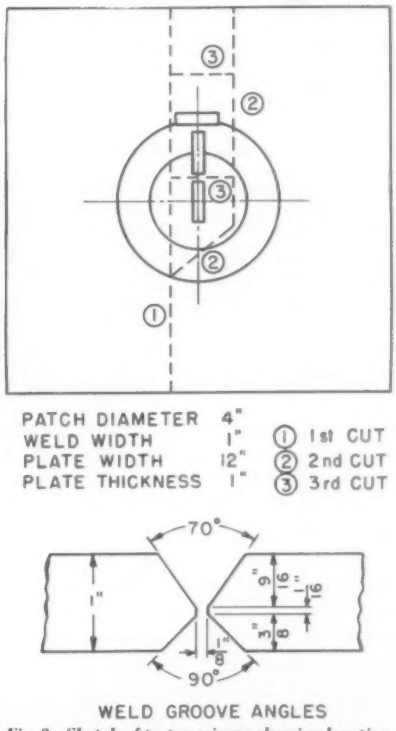

Fig. 2 Sketch of test specimen showing location of strain gages, pattern of saw cuts and weld preparation

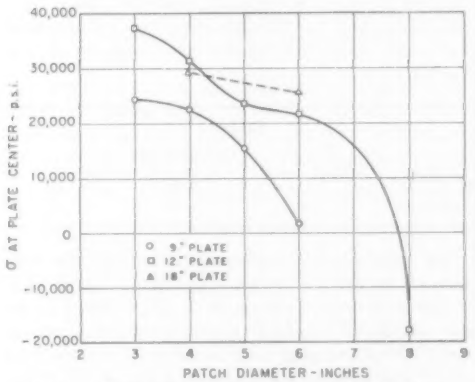

Fig. 3 Stress at plate center vs. patch diameter

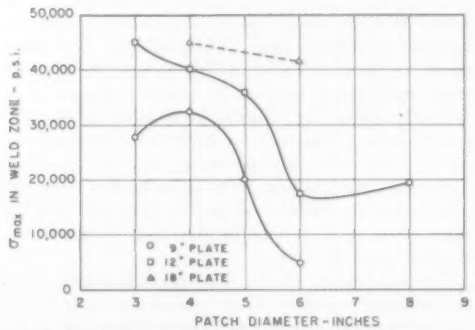

Fig. 4 Maximum circumferential stress in weld zone vs. patch diameter

Readings of the gages were taken before and after cutting to determine the elastic strains.

Results

Stresses were computed from the measured strains by conventional combined stress analysis. The residual stress level of the test specimens was most accurately determined at the center of the patch. The strains from the top and bottom gages at all positions were averaged to get the strain used in the stress calculations. Plots of the resultant residual stresses at the center versus the patch diameter are presented in Fig. 3. The residual tensile stress at the plate center is of the order of the yield stress for the smaller size patches in the 12- and 18-in. plates and decreases with an increase in patch size. The compression stress at the center of the 8-in. patch in a 12-in. plate reverses the trend of tension stress in the patch. The stress level of the 9-in. plate is considerably below that of the two larger size plates. For the small patch sizes, the stress level of the 12-in. plates exceeds that of the 18-in. plates. As the patch size increases, the stress level of the 18-in. plates begins to exceed that of both the smaller size plates. The magnitude of the residual stress for the smallest patch sizes in the 12-in. plate exceeds or equals the yield stress of the untreated, hot-rolled plate. The yield stress and the ultimate stress for the untreated plate, determined from simple tension tests, are noted in Table 1.

Table 1

Test bar	*Tensile yield stress, psi*	*Ultimate tensile stress, psi*	*Elongation, %*
Longitudinal	34,700	62,800	33
Transverse	31,600	62,800	32

The maximum circumferential stress in the weld zone versus patch diameter is plotted in Fig. 4. The strains were determined by strain gages placed so the gage section of a radially placed gage and a circumferentially placed gage were on the weld and adjoining area. The strains from matching gages on the underside of the plate were averaged with the readings from the top gages. The weld zone was approximately 2 in. wide. It was found that the circumferential stress exceeded the radial stress. The magnitude of residual stress was greatest for the 12-in. plate. The smallest diameter patches resulted in residual stresses considerably above the uniaxial yield stress of the untreated plate. The curve for the 18-in. plate was determined from only two specimens and was therefore drawn as a straight line. The stress level of the 12-in. plate is greater than that of the 9-in. plate and is of the same order of magnitude as the 18-in. plate at the smallest patch diameters.

The comparison of the plate sizes is better interpreted from a plot of stress against the ratio of the patch size to the plate size. Figure 5 shows that the effect of increasing the patch size is to decrease the residual stress level. This effect follows a curved line relationship which is the same for all plate sizes. For the smaller diameter patches, the stress level attained in the 12-in. plate exceeds the degree of residual stress present in the 9- and 18-in. plates.

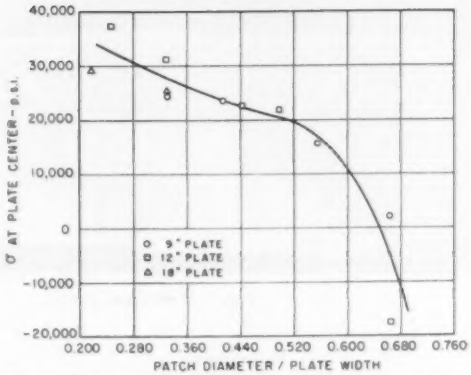

Fig. 5 Stress at plate center vs. patch diameter/plate width

Figure 6 shows how the maximum circumferential stress in the weld zone varies with the ratio of patch size to plate size. The stress level decreases with an increase in the ratio. The smaller volume of metal in the 9-in. square plate cannot provide the restraint necessary to induce residual stresses of yield stress magnitude in the weld zone.

Discussion

The data reported herein indicate that residual tension stresses are present at the center and in the weld zone of circular-patch weld-test specimens. The magnitude of these stresses are of the order of the yield stress of the plate material when the patch diameter to plate width ratio is in the range 0.200 to 0.300, and is lower for specimens of larger ratio. The region of residual tension stresses extended from the center of the plate outward beyond the weld zone. The tensile stresses

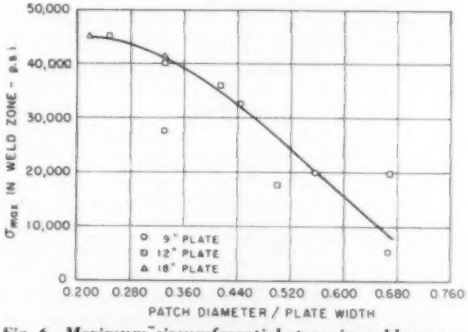

Fig. 6 Maximum circumferential stress in weld zone vs. patch diameter/plate width

were measured both in a radial direction and in a circumferential direction. At the center, symmetry resulted in equal stress magnitudes in all directions. Away from the plate center, the circumferential stress exceeded the radial stress. To balance the forces circumferential compression stresses occur at the plate's periphery.

The weld zone is, therefore, subjected to residual biaxial tension stresses. High residual tension stresses in weld tests presumably provide the most critical condition for evaluating the strength of the weld and the surrounding heat-affected zone. Biaxial stresses of the order of the yield stress, as obtained in this circular patch test, fulfill the conditions necessary for a severe weldability test.

As the patch diameter is increased in a plate of given size, a diameter is reached where the pattern of residual stresses in the plate is changed. The center stress changes from tension to compression.

The effect of varying the patch size is to change the magnitude of the residual stress, which continually decreases with increasing patch diameter. However, the decrease is not linear.

The effect of varying the plate size is significant in that it does not have a substantial effect on the residual stresses induced, provided that the patch diameter to plate width ratio is the same and the plate size exceeds 9 in. The use of 12-in. wide plate thus appears to be satisfactory for circular-patch weld-test specimens of 1 in. thickness.

In the past, the use of circular-patch weld tests depended upon the discovery of cracks in the weld or adjacent zone as the criteria for acceptable performance of the joint. Cross sections of the 3 in. diam and 4-in. diam patches from both the 12-in. wide and 18-in. wide plates were examined for cracks, but none were found. However, the steel used was a ductile mild steel not susceptible to underbead cracking.

The altered metallurgical structure in the weld and heat-affected zones increased the yield stress of the base metal over the 32,000 psi yield stress of the as-received, hot-rolled plate. For this reason, values of residual stress somewhat above 40,000 psi were obtained in the weld and heat-affected zone of the plates with small diameter patches.

The residual stress in the hot-rolled, unwelded plate and the stresses introduced by the flame cutting operations were determined in a 12-in. wide plate from which a 4-in. diam patch had been cut. The results indicate that the magnitude of these stresses could be, at the most, only a minor contributing factor to the resultant stress after welding. The effective residual stress pattern of the unwelded test plate is severely altered by the effect of the thermal gradients created during the welding operation.

SUMMARY AND CONCLUSIONS

1. Tension stresses, both radial and circumferential, extend from the center of the plate outward beyond the weld zone for patch diameter to plate width ratios from 0.200 to 0.650. Circumferential compression stresses exist at the periphery of the plate.

2. Residual tension stresses of the order of the yield stress of the material are present in specimens where the patch diameter to plate width ratio is in the range 0.200 to 0.300.

3. As the patch diameter is increased in any given size plate, the residual tension stresses are reduced in magnitude.

4. The 12-in. wide plate provides sufficient constraint to result in residual tension stress of the order of the yield stress of the material. The 18-in. wide plate provides residual stresses of the same magnitude for the same patch diameter to plate width ratio.

5. The 9-in. wide plate does not provide sufficient constraint to result in residual tension stresses of yield stress magnitude.

6. Plates with very small patches are undesirable because the cooling rate of the weld deposit is lower than in a normal butt weld. Patches 4 to 5 in. in diameter seem to offer the best geometry for test specimens.

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Porosity in Mild Steel Weld Metal

A study of the effect on the formation of voids in weld metal as affected by deoxidation practice weld metal solidification rates, base plate surface contaminate and arc welding atmospheres

by Donald Warren and R. D. Stout

INTRODUCTION

In order to provide the proper background for the present study of porosity in mild steel weld metal, the authors have discussed in an earlier paper[1] the initiation of porosity in weld metal, the various factors contributing to the formation of gas cavities and the physical nature of these cavities. For this investigation, the shielded-inert-gas metallic-arc, or sigma, process was selected to study the effect on the formation of voids in weld metal of such variables as electrode and base plate deoxidation level, weld metal solidification rates, base plate surface contaminants and arc welding atmospheres. Because it is basically simple, involving only an arc between an consumable wire electrode and the work piece in an inert gas shield of argon or helium, the sigma process was considered to be ideal for such a study. The complicated slag-metal and arc atmosphere-metal reactions usually encountered in other welding processes are completely eliminated.

EXPERIMENTAL DETAILS

Apparatus

All of the welds in this study were made within a specially constructed, airtight steel chamber having provisions for automatic welding within a controlled atmosphere. (See Fig. 1.) The wire welding electrode was introduced into the chamber through a copper guide tube mounted in the top. The weld was made by moving the base plate along under the end of the guide tube in a longitudinal direction.

The welding electrode could be fed at rates up to 420 ipm by means of a Linde FSM-2 Rod Feed and Control Assembly connected to the guide tube in the welding chamber with $^1/_4$-in. soft copper tubing. The guide tube itself was insulated from the chamber and was

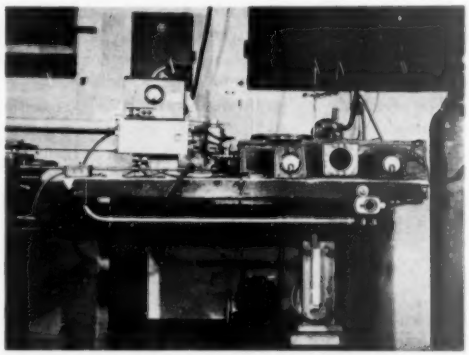

Fig. 1 Apparatus used for automatic welding within a controlled atmosphere chamber

designed with an easily adjusted seal to allow quick replacement of fused tubes. The travel feed mechanism consisted of a sliding plate guided in loose-fitting tongue and groove joints between two side plates and attached by a $^1/_2$-in. round shaft to the screw feed of a modified lathe. An adjustable packing gland was used to provide an effective seal around the shaft where it entered the chamber. Welding speeds of $2^5/_8$ to $19^1/_2$ ipm could be obtained with this arrangement.

The source of direct current for welding was a selenium rectifier transformer consisting of twin 400-amp units. The positive terminal of this unit was connected to the copper guide tube of the welding chamber via the relay box of the Linde unit, whereas the negative terminal was attached directly to the travel feed shaft.

Of welded construction, the welding chamber had inside dimensions of 5 in. high, 8 in. wide and 29 in. long. Access to the chamber for the insertion and removal of test plates and for cleaning was provided by an 8-in. round opening in the top. During welding, this opening was sealed by means of a bolted cover plate and rubber gasket. The chamber was equipped with a pressure gage and three separate valves: one for evacuation, one for admittance of gas mixtures and one for release of gases during welding. A Pressovac pump was employed to evacuate the chamber before purging with argon or other gases. A constant

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Table 1—Chemical Analyses of Steel Base Plates

	Designation and classification of steel					
	DB Specially killed, %	*BF Al-killed, %**	*BC Semikilled, %*	*WB Rimmed, %*	*U Killed, %*	*H Rimmed, %*
C	0.14	0.21	0.21	0.21	0.16	0.25
Mn	1.29	0.78	0.78	0.36	0.54	0.36
Si	0.29	0.08	0.08	0.01	0.20	...
P	0.023	0.013	0.013	0.016	0.020	0.016
S	0.020	0.031	0.031	0.029	0.024	0.031
Cr	0.05	...	...	0.09	0.02	0.04
Ni	0.06	...	...	0.15	0.04	0.15
Cu	...	...	...	...	0.06	0.19
Ti	0.014	...	...	...	...	...
Total Al	...	0.043	0.008	...	0.041	...
Al as Al_2O_3	...	0.005	0.002	...	0.003	...

* This steel is the same as Steel BC except for the addition of aluminum to the ingot mold.

supply of fresh gas at the arc was insured by passing the gas, after it had entered the chamber through the intake valve, into a single coil of copper tubing and allowing it to escape through fine holes in the underside of the coil just above the arc. The welding arc could be viewed through a lucite-covered opening that was protected from spatter and excessive heat by an inner shield of mica. Operating controls consisted of a starting button for energizing the main relay supplying current to the copper guide tube, an inching button for advancing the electrode gradually, a rod feed control setting, and an off-on switch for operating the travel speed.

The complete welding apparatus is shown in Fig. 1; the welding chamber is on the right side of the bench and the rod feed assembly is to the left. Mounted below are the vacuum pump and mercury manometer. The edge of the lathe used for moving the travel plate can be seen at the extreme left.

Materials

The bulk of the welds in this investigation were of the bead-on-plate variety and were made on steel plates approximately 3 in. wide by 12 in. long, and usually $^3/_4$ in. thick. Where the size of the weld permitted, two welds were laid on the same plate. The plates were always surface ground to remove any rust, scale or surface defects. Before welding, the plates were thoroughly degreased with carbon tetrachloride. Plates of six different steels were used; these differed principally in deoxidation practice and ranged from rimmed to specially killed types. The complete chemical analyses for these steels are given in Table 1, while the vacuum fusion analyses for oxygen, hydrogen and nitrogen are listed in Table 2.

Table 2—Vacuum Fusion Analyses of Steel Base Plates

		%		
Steel	*Classification*	*O*	*H*	*N*
DB	Specially killed	0.003	0.00022	0.004
BF	Al-killed	0.0015	0.000064	0.003
BC	Semikilled	0.0066	0.00013	0.003
WB	Rimmed	0.009	0.0003	0.001
U	Killed	0.005	0.00007	0.001
H	Rimmed	0.006	0.00007	0.002

The wire electrodes employed in this study were all $^1/_{16}$ in. in diameter but varied in type of steel from rimmed to specially killed. Because the killed steel electrode (generally available commercially as Oxweld No. 32) was the most widely used, three different lots were consumed, one bare wire and two copper coated. The Oxweld No. 36, Oxweld No. 43 and Lot 5-673 were specially drawn lots of wire and were used in the bare condition. Table 3 lists the carbon, manganese and silicon analyses for these electrodes, and Table 4 gives

Table 3—Chemical Analyses of Welding Electrodes

			%		
Electrode	*Lot No.*	*Classification*	*C*	*Mn*	*Si*
Oxweld No. 32	1 (bare)	Killed	0.09	1.13	0.27
Oxweld No. 32	2 (copper coated)	Killed	0.15	1.10	0.25
Oxweld No. 32	3 (copper coated)	Killed	0.17	1.02	0.20
Oxweld No. 36	.....	Semikilled	0.16	1.79	0.05
Oxweld No. 43	.....	Rimmed	0.051	0.20	0.02
Lot 5-673	.....	Specially killed*	0.038	0.68	0.47

* 0.12% Al, 0.13% Zr and 0.087% Ti.

Table 4—Vacuum Fusion Analyses of Welding Electrodes

			%		
Electrode	*Lot No.*	*Classification*	*O*	*H*	*N*
Oxweld No. 32	1 (bare)	Killed	0.019	0.00045	0.007
Oxweld No. 36	.....	Semikilled	0.021	0.00035	0.003
Oxweld No. 43	.....	Rimmed	0.042	0.00019	0.007
Lot 5-673	.....	Specially killed	0.049	0.00043	0.007

the results of vacuum fusion analyses for the same electrodes.

The atmosphere in which most of the welds were made was welding grade argon having a minimum purity of 99.8% with the principal contaminant being nitrogen. (See Table 5 for a complete analysis of composition.) Some welds were laid in high purity argon (99.99%) to evaluate the effect of the small amounts of impurities present in the welding grade argon. In the study of gas impurities up to 10%, specially prepared mixtures of hydrogen, oxygen and nitrogen in high-purity argon were used. Where more than 10% of a gaseous impurity was desired in the welding atmosphere, a commercial grade of hydrogen, oxygen or nitrogen was blended with welding grade argon.

Table 5—Composition of Welding Grade Argon

Minimum purity:	99.8% argon.
Nitrogen content:	Maximum of 0.19%, usually about 0.1%.
Oxygen content:	Maximum of 20 parts per million.
Hydrogen content:	Maximum of 40 parts per million.
Total of gaseous impurities *other* than nitrogen:	Approximately 100 parts per million.
Moisture content:	9 grains per 1000 cu ft or less.

Procedure

The ground and degreased steel plates were inserted into the chamber and fastened to the sliding plate by setscrews at each end. The copper guide tube for the wire electrode was then adjusted so that the end of it was approximately $^3/_4$ in. above the top surface of the plate (this had proved to be the optimum distance for most of the welding conditions). Next the cover was bolted over the access opening, and the copper guide tube was tightened in place and sealed with a piece of rubber tubing clamped at one end. The chamber was then evacuated to a pressure of 5–7 mm of mercury after which the valve to the argon supply was opened and the chamber allowed to flush mechanically until the pressure reached approximately 20 cm. The pump was then shut off and the chamber was filled with argon at a rate of 60 cfh or higher. Two evacuation and purging cycles were used prior to each weld. With the small leak rate present (0.5 mm/min at a pressure of 5 mm) and the short times required for purging (0.6 min), approximately 0.01% of the original air remained in the chamber. This is much less than the impurities in the welding grade argon used for most of the welds. When the high-purity argon (99.99%) was used, the chamber was purged three times at a maximum pressure of 0.5 mm and special precautions were taken to reduce the leak rate.

After the final purging, the gas flow was set at the desired level (10–15 cfh) and the pressure relief valve was used to maintain the gage pressure within the chamber at 3–5 psi. The wire electrode was inserted into the guide tube and the connecting tubing from the rod feed motor was fastened to the top of the guide tube. Next, the electrode was advanced down the guide tube with the inching button until it made contact with the plate. The current, rod feed and travel speed controls were then set at predetermined values. The arc was initiated by pressing the button closing the current relay. The drop in voltage from the open circuit value to the arc value actuated another relay which started the rod feed motor. At the same time, the travel speed switch was manually closed and the weld was in progress. The pressure increase within the chamber upon initiation of the arc was very rapid and had to be relieved through manual manipulation of the pressure release valve.

Voltage and current readings were taken from the meters at each side of the viewing window while the operating characteristics of the arc including type of transfer, amount of spatter and stability were visually noted. The behavior of the weld puddle was also observed as closely as was possible in the short time available (30 sec to 3 min).

There was no provision for automatic voltage control in this apparatus; the generator and rod feed controls were merely set at values known from trial welds to give both the desired current and a normal arc. Because of the constant rod feed, the achievement of steady welding conditions was dependent upon the self regulating characteristics of the arc.[2] This was generally no problem under normal welding conditions where a regularly shaped weld bead was obtained.

When the weld approached the end of the plate, the travel feed was stopped by an automatic cut-off switch; at the same time the arc was extinguished by pushing the button opening the main current relay. The weld was allowed to cool slightly and then was removed from the chamber to finish cooling. Any drops of weld spatter were knocked off and the plate was wire brushed.

The welds were radiographed on fine-grained film with 0.010-in. thick lead foil screens using a 150-kv X-ray unit (for plates up to $^3/_4$ in. thick). This technique afforded a radiographic sensitivity of about 1%. The processed radiographs were inspected on a fluorescent viewer, and the amount of porosity in the weld was determined by counting (where countable) the number of holes falling within three size ranges: diameter of hole $< {}^1/_{32}$ in., $^1/_{32}$ in. $\leq$ diameter of hole $< {}^1/_{16}$ in. and diameter of hole $\geq {}^1/_{16}$ in. In these porosity counts, the crater and the first inch of weld were disregarded. The final evaluation of the porosity was given in terms of the number of holes per inch of weld in each of the size ranges. The shape of the voids and their distribution throughout the weld were also noted.

Many of the welds were sectioned, ground and macroetched in order to observe the size, form and location of the voids in the weld. Tracings of the weld cross sections at magnifications of 2 to 3 × were also made. These were used to determine the depth and area of penetration, width of weld nugget and nugget area.

Samples were removed from a number of the welds and chemically analyzed for carbon, manganese and silicon. Vacuum fusion analyses were also run on two of the welds.

Table 6—Typical Welding Conditions and Weld Dimensions for Various Electrode-Base Plate Combinations

All of the welds in this series were made in welding grade argon on $^3/_4$-in. thick base plate

Welding electrode	Base plate, steel	Welding conditions: Current, amp	Voltage, v	Travel speed, ipm	Rod feed, ipm	Weld dimensions: Width of nugget, in.	Depth of penetration, in.	Nugget area, sq in.	Area of penetration, sq in.	Dilution, %
Killed*	Killed (BF)	240–250	28–31	$2^3/_8$	142	0.96	0.18	0.28	0.10	36
		245–250	28–29	$7^1/_2$	142	0.63	0.085	0.10	0.036	36
		250	28–29	$19^1/_2$	142	0.33	0.067	0.038	0.012	30
Killed*	Killed (BF)	390–400	28–30	5	294	1.04	0.31	0.35	0.16	46
		390	31	10	294	0.79	0.33	0.22	0.12	55
		390–400	28–29	$19^1/_2$	294	0.46	0.29	0.11	0.056	52
Semikilled (No. 36)	Killed (BF)	390–400	28–29	5	286	0.99	0.36	0.38	0.17	45
Rimmed (No. 43)	Killed (BF)	400–410	27–28	5	286	0.89	0.35	0.33	0.14	42
Rimmed (No. 43)	Rimmed (WB)	430	22	5	286	0.80	0.46	0.35	0.16	46

* These welds were made with either Oxweld No. 32 (bare) or Lot 5-673.

DISCUSSION OF RESULTS

I. Welding Conditions

A general discussion of the welding conditions involved in this study is given here in order to avoid a detailed presentation in the discussion of porosity. Originally, two levels of current were selected for investigation: 250 amp, which was about the lowest value at which spray transfer was obtained, and 400 amp, which was close to the upper limit of the apparatus. Later experiments were confined almost exclusively to the 400 amp level. The welding voltage reported here represents the sum of the arc voltage and the resistance (IR) drop along the wire electrode from the end of the guide tube to the arc. The resistance component of the voltage was kept approximately constant for a given combination of current and rod feed by maintaining the copper guide tube at a fixed distance ($^3/_4$ in.) above the base plate.*

Electrode-Base Plate Combinations. A group of representative welding conditions and the resulting weld dimensions for various electrode-base plate combinations can be found in Table 6. Cross sections of the first six welds in this table are shown in Figs. 2 and 3. The welding conditions for two of the killed electrodes, Oxweld No. 32 (bare) and Lot 5-673, were quite similar. However, the welding voltage was appreciably higher for the copper-coated Oxweld No. 32 than for the other two killed electrodes: 33–35 v compared to 30–32 at the 400 amp level. The weld dimensions for any of the killed electrodes did not vary significantly from one type of base plate to another.

Fig. 2 Weld cross sections: Killed electrode on killed base plate ($^3/_4$ in. thick), welding grade argon, 250 amp, $19^1/_2$, $7^1/_2$ and $2^3/_8$ ipm. 1 ×

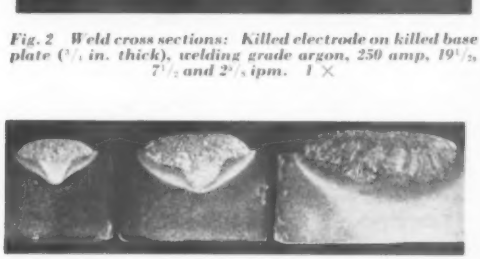

Fig. 3 Weld cross-sections: Killed electrode on killed base plate ($^3/_4$ in. thick), welding grade argon, 400 $19^1/_2$, 10 and 5 ipm. 1 ×

The semikilled electrode (Oxweld No. 36) produced weld beads that were slightly higher and narrower than those made with the killed electrodes. The welding conditions and weld dimensions for Oxweld No. 36 were similar for all of the base plates except for the rimmed Steel H where the weld deposits were often quite high, resulting in low voltages (26–27 v) and high currents (430–440 amp). The rimmed electrode (Oxweld No. 43) produced slightly high and narrow weld beads on killed base plate; but on semikilled and rimmed steel base plate, the weld deposits from this electrode were extremely high and narrow with accompanying low voltages (25–27 v) and high currents (430–450 amp).

Arc Atmosphere. The addition of certain gases to the welding atmosphere caused marked changes in the welding conditions, particularly the arc voltage. When present in quantities of 10% or more in the arc atmosphere, both hydrogen and nitrogen increased the arc voltage, the former more than the latter (39–40 v compared to 37–38 v). Also, both gases appeared to raise the level of current density required for spray transfer; i.e., spray transfer was no longer obtained at 250 amp. The addition of 10% hydrogen caused increased spatter, especially at the longer arc lengths. In an atmosphere of 100% hydrogen, a welding arc could be initiated only with great difficulty, and the arc that resulted was quite erratic. The use of a 100% nitrogen atmosphere caused considerable spatter and resulted in a completely globular type of metal transfer. Similar to hydrogen, the addition of water vapor to the arc atmosphere (by bubbling welding grade argon through water) increased the arc voltage, particularly where the arc lengths were longer. However, the type of metal transfer was not appreciably affected by the presence of water vapor.

Fig. 4 Weld bead: Killed electrode on killed base plate (3/4 in. thick), 99.99% argon, 400 amp., 5 ipm. 0.25 ×

In contrast to hydrogen and nitrogen, the addition of oxygen to welding grade argon in quantities of 5% or more lowered the current density required for spray transfer and also stabilized the arc. This property of oxygen has served as the basis of a commercial development in the sigma welding process.[3] When present in quantities of 10% or more, oxygen lowered the arc voltage. Use of the higher percentages of oxygen resulted in a light slag coating on the weld bead.

The welding conditions in high purity argon were identical to those in welding grade argon. See Fig. 4 for a photograph of a weld laid in 99.99% argon at 400 amp, 5 ipm using Oxweld No. 32 on steel BF.

II. Effect of Welding Conditions on the Formation of Porosity

Current Density. In a preliminary investigation of the effect of welding conditions on the formation of porosity, it was noted that welds made with a killed steel electrode at approximately 250 amp (82,000 amp/sq in.) contained little or no porosity while those made at approximately 400 amp (131,000 amp/sq in.) contained a total of one to eight holes per inch of weld. Of 38 welds made in argon at 250 amp and at various travel speeds using either a killed or semikilled electrode, voids were found in only eight; and the total number of cavities in any of the eight welds was never over one hole per inch of weld.

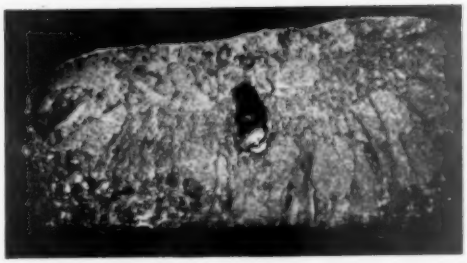

Fig. 5 Worm hole porosity: Killed electrode on rimmed base plate (1/4 in. thick), welding grade argon, 250 amp, 2 1/4 ipm. 3.2 ×

An example of worm-hole porosity found in one of the welds made at 250 amp is shown in Fig. 5. Those welds made at 250 amp on rimmed-steel base plate using a rimmed-steel electrode were subject to gross porosity and will be discussed later.

On the basis of the preliminary results, a series of welds were laid at approximately 300, 400 and 450 amp on killed base plate using a killed electrode. The travel speed was increased with increasing current level in order to provide a constant heat input. The results of this experiment are given in Table 7 while Fig. 6 shows the cross sections of welds made at the three current levels. The total amount of porosity present in

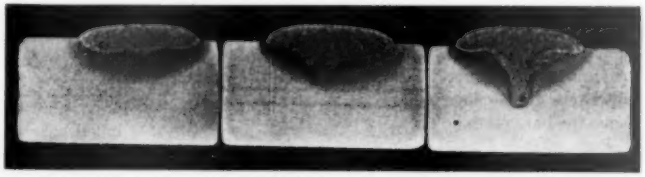

Fig. 6 Weld cross sections: Killed electrode on killed base plate (3/4 in. thick), welding grade argon. Left: 300 amp, 7 1/2 ipm. Center: 400 amp, 10 ipm. Right: 450 amp, 11 3/4 ipm. 1 ×

Table 7—Effect of Current Density on the Formation of Porosity

All of the welds in this series were made in welding grade argon on 3/4-in. thick base plate of Steel BF using Oxweld No. 32 (Lot No. 3)

Current density, amp/sq in.	Welding conditions			
	Current, amp	Voltage, v	Travel speed, ipm	Heat input, joules/in.	Rod feed, ipm
96,000	290–300	35–36	7 1/2	84,000	204
126,000	380–390	33–34	10	77,500	302
145,000	440–450	36–37	11 3/4	83,000	418

Current density, amp/sq in.	Weld dimensions				
	Width of weld nugget, in.	Depth of penetration, in.	Nugget area, sq in.	Area of penetration, sq in.	Dilution, %
96,000	0.86	0.14	0.17	0.081	47
126,000	0.90	0.27	0.23	0.13	56
145,000	0.92	0.40	0.22	0.11	49

Current density, amp/sq in.	No. of holes/in. of weld		
	$D < 1/32$ in.	$1/32$ in. $\leq D < 1/16$ in.	$D \geq 1/16$ in.
96,000	0	0	0
	0.4	0.1	0
126,000	3	1	0
	2	0.4	0
145,000	10	4	0.9
	11	3	0.1

the welds increased quite markedly with current density. This is in accord with previously published data[4] showing appreciable porosity in welds made with the sigma process at current densities above 98,000 amp/sq in.

Figures 3 and 5 show a type of weld contour peculiar to the higher levels of current. The high local concentration of energy directly under the end of the small wire electrode produced a "fingerlike" projection into the base plate. The use of slower travel speeds decreased the sharpness of this "finger." The depth of penetration as given in Table 6 also indicates the marked effect of current density on the shape of the weld nugget.

The bulk of the voids observed in cross sections of the welds were located along or near the fusion line. In the welds laid at the highest currents, the gas cavities were largely confined to the "finger" region of the weld nugget. It is believed that the greater number of voids produced by the higher current densities was due to both the increased depth of penetration and to the unusual shape of the weld nugget. The greater the depth of penetration, the greater the distance the gas bubbles have to travel through the melt before making their escape at the surface and the greater the likelihood of their being entrapped. Secondly, the "finger" region of the weld nugget was subject to more rapid cooling because of the larger contact area available for heat transfer. Because of this, less time was available for the escape of gas bubbles. Another possible reason for the increased formation of porosity at the higher currents was the decreased droplet size and a correspondingly greater reaction with any gaseous impurities present in the arc atmosphere.

Travel Speed. Because the use of slower travel speeds reduced the sharpness of the "finger" region of the weld nugget and also decreased the cooling rate (due to the higher heat inputs), it might be expected that a slower welding speed would result in the formation of fewer voids. However, no consistent trend was observed between the amount of porosity and the travel speed in the range of $2^5/_8$ to 15 ipm. But when a travel speed of $19^1/_2$ ipm was used with high currents, the slightest instability in the welding conditions resulted in the formation of irregularly shaped voids in the weld.

Eleven out of 33 welds laid at 400 amp, $19^1/_2$ ipm contained from one to 19 large irregular cavities. The majority of these cavities were caused by momentary interruptions in rod feed which at the high travel speeds produced mechanical imperfections or bridging in the weld. Figure 7 shows such a defect extending the entire width of the finger while Fig. 8 is a radiograph of a weld having a number of these imperfections spaced at fairly regular intervals. Similar difficulties with the formation of mechanical porosity at welding speeds above 20 ipm were encountered by Herbst and McElrath.[4]

Fig. 7 Mechanical defect in 400 amp, $19^1/_2$ ipm Weld: Killed electrode on rimmed base plate ($1^1/_4$ in. thick), welding grade argon. 15 ×

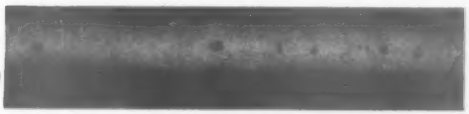

Fig. 8 Radiograph showing imperfections in 400 amp, $19^1/_2$ ipm Weld: Killed electrode on rimmed base plate ($^3/_4$ in. thick), welding grade argon. 0.7 ×

Table 8—Effect of Cooling Rate or Base Plate Thickness

All of the welds in this series were made in welding grade argon at approximately 400 amp, 5 ipm using Oxweld No. 32 (Lot No. 1)

Steel and classification	Plate thickness, in.	No. of holes/in. of weld: $D < {}^1/_{32}$ in.	$^1/_{32}$ in. $\leq D < {}^1/_{16}$ in.	$D \geq {}^1/_{16}$ in.	Composition of weld metal, %: C	Mn	Si
U (killed)	$^1/_2$	0.5	0.4	0			
	$^3/_4$	2	0.8	0.2	0.12	0.83	0.16
	$1^1/_4$	0.8	0.4	0			
H (rimmed)	$^1/_2$	0.7	0.2	0	0.17	0.78	0.17
	$^3/_4$	10	5	0	0.20	0.77	0.16
	$1^1/_4$	0.6	0.5	0.3	0.13	0.73	0.17

All of the welds in this series were made in welding grade argon at approximately 400 amp, 10 ipm on Steel U using Oxweld No. 32 (Lot 3)

Plate thickness, in.	No. of holes/in. of weld: $D < {}^1/_{32}$ in.	$^1/_{32}$ in. $\leq D < {}^1/_{16}$ in.	$D > {}^1/_{16}$ in.	Weld dimensions: Width of nugget, in.	Depth of penetration, in.	Nugget area, sq in.	Area of penetration, sq in.	Dilution,
$^3/_4$	8	0.9	0	0.88	0.28	0.25	0.14	56
	4	0.9	0					
$1^1/_4$	0.8	0.6	0	0.85	0.26	0.22	0.12	54
	0.5	0	0					

Table 9—Reproducibility Study

All of the welds in this series were made in welding grade argon at approximately 400 amp, 10 ipm on $^3/_8$-in. thick base plate of Steel BF using Oxweld No. 32 (Lot No. 2)

Weld designation	*No. of holes/in. of weld*			*Composition of weld metal, %*		
	$D < {}^1/_{32}$ *in.*	${}^1/_{32}$ *in.* $\leq D <$ ${}^1/_{16}$ *in.*	$D >$ ${}^1/_{16}$ *in.*	*C*	*Mn*	*Si*
A	2	0.4	0	0.13	0.92	0.16
B	1	0.1	0	---	---	---
C	2	0.1	0	---	---	---
D	2	1	0	---	---	---
E	1	0.2	0	---	---	---
F	8	0.9	0.1	0.18	0.87	0.16

Cooling Rate or Base Plate Thickness. The effect of cooling rate upon the formation of gas cavities was studied by laying a series of welds on base plates of varying thickness using a killed steel electrode. The results are listed in Table 8. In the first group of data, the greatest amount of porosity was produced in welds laid on base plates of intermediate thickness, while in the second group of data the larger number of voids were present in welds laid on the $^5/_8$-in. thick base plate. Because, in some cases, the use of different base plate thicknesses resulted in variations in weld dimensions and weld metal composition, the changes in porosity could not be attributed to the effect of cooling rate alone.

III. *Reproducibility of Porosity in Welds*

In order to determine the variation in porosity to be expected from one weld to another when these welds are made under as nearly the same conditions as possible, a series of six welds were laid at approximately 400 amp., 10 ipm in welding grade argon on killed-steel base plate using a killed-steel electrode. The results of this study are summarized in Table 9. Consistent results were obtained except for Weld F, which showed a higher level of porosity. Both the welding conditions and the resulting weld dimensions were practically identical for all six of the welds; the only significant difference between Weld F and Weld A was the appreciably higher carbon content of the former. As can be seen from Fig. 9, the deoxidizing power of carbon at 1600° C approaches that of silicon at about 0.17–0.18% C. Thus, in weld metal which has a composition of 0.16% Si and 0.18% C, the carbon should be the stronger deoxidizer and could therefore react with oxygen present to form carbon monoxide. Where the carbon monoxide reaction is active, the possibility of

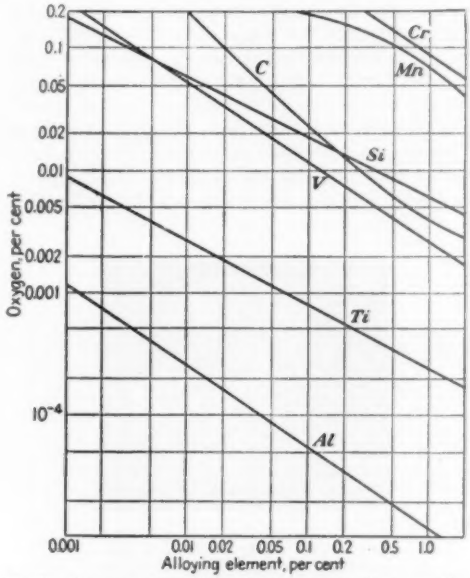

Fig. 9. A comparison of deoxidizing powers for a number of elements at 2900° F (1600° C)., (From "Basic Open-Hearth Steelmaking," American Institute of Mining and Metallurgical Engineers, New York, 1944)

Table 10—Welds Made with a Killed Electrode on Various Base Plates

All of the welds in this series were made in welding grade argon at approximately 400 amp on $^3/_8$-in. thick base plate

Welding electrode	*Steel and classification*	*Travel speed, ipm*	*No. of holes/in. of weld*			*Composition of weld metal, %*		
			$D < {}^1/_{32}$ *in.*	${}^1/_{32}$ *in.* $\leq D <$ ${}^1/_{16}$ *in.*	$D \geq {}^1/_{16}$ *in.*	*C*	*Mn*	*Si*
Oxweld No. 32 (Lot No. 1)	BF (killed)	5	0.7	0	0	0.13	0.92	0.17
	WB (rimmed)		1	0.2	0.3	0.13	0.70	0.10
	DB (specially killed)		0.8	0.2	0.2			
	U (killed)	5	2	0.8	0.2	0.12	0.83	0.16
	H (rimmed)		10	5	0	0.19	0.77	0.16
	BF (killed)	10	0.4	0	0			
	WB (rimmed)		5	0.9	0			
Oxweld No. 32 (Lot No. 2)	BF (killed)	5	5	1	0	0.18	0.92	0.16
	BC (semikilled)		5	0.3	0			
	WB (rimmed)		6	1	0	0.17	0.71	0.13
	DB (specially killed)		6	0.7	0			
Lot 5-673	BF (killed)	5	0.4	0.4	0	0.11	0.71	0.29
	WB (rimmed)		0	0	0	0.08	0.53	0.27

Table 11—Welds Made with a Semikilled Electrode on Various Base Plates

All of the welds in this series were made in welding grade argon at approximately 400 amp. Base plate of Steels BF, BC and WB was $^3/_4$ in. thick while that of Steels U and H was $^5/_8$ in. thick

Steel and classification	*Travel speed, ipm*	*No. of holes/in. of weld*			*Composition of weld metal, %*		
		$D < {}^1/_{32}$ *in.*	$^1/_{32}$ *in.* $\leq D < {}^1/_{16}$ *in.*	$D \geq {}^1/_{16}$ *in.*	*C*	*Mn*	*Si*
BF (killed)	5	8	5	0.2	0.16	1.30	0.06
WB (rimmed)		9	8	3	0.16	1.12	0.03
BF (killed)	10	16	9	0	0.18	1.29	0.05
BF*		11	2	0.1			
BF*		16	5	0.1			
BC (semikilled)		13	8	0.3			
WB (rimmed)		13	8	0.8	0.18	1.01	0.01
U* (killed)	10	21	2	0			
U		13	2	0			
H (rimmed)		16	5	2			
H		18	4	0.3			
H		16	6	2			
H		11	5	0.4			

* These welds were made in 99.99% argon.

Table 12—Welds Made with a Rimmed Electrode on Various Base Plates

The welds in this series were made in welding grade argon at both 250 and 400 amp. Base plate of Steels BF, BC and WB was $^3/_4$ in thick while that of Steels U and H was $^5/_8$ in. thick

Steel and classification	*Travel speed, ipm*	*No. of holes/in. of weld*			*Composition of weld metal, %*		
		$D < {}^1/_{32}$ *in.*	$^1/_{32}$ *in.* $\leq D < {}^1/_{16}$ *in.*	$D \geq {}^1/_{16}$ *in.*	*C*	*Mn*	*Si*
			400-amp. welds				
BF (killed)	5	2	0.5	0	0.11	0.45	0.05
WB (rimmed)			Herringbone porosity		0.13	0.27	0.01
BF (killed)		6	1	0			
BF*		12	1	0			
BF*	10	12	3	0			
BF*		15	5	0			
BC (semikilled)		12	8	0.4			
WB (rimmed)			Herringbone porosity				
U (killed)		13	1	0			
U		17	5	0			
H* (rimmed)	10		Herringbone porosity				
H			Herringbone porosity				
H			Herringbone porosity				
			250-amp welds				
BF (killed)	$7^1/_2$	0	0	0			
BC (semikilled)	10	0	0	0			
WB (rimmed)	$7^1/_2$		Herringbone porosity				

* These welds were made in 99.99% argon.

porosity is always increased. Subsequent data will show that larger numbers of voids are formed where the carbon content of the weld metal is higher.

IV. Influence of Deoxidation Level on the Formation of Gas Cavities

Effect of Base Plate Deoxidation Practice on Welds Made with Killed, Semikilled and Rimmed Electrodes. The results of welding on various types of steel base plate with killed, semikilled and rimmed electrodes are given in Tables 10, 11 and 12. With the killed or semikilled electrodes, the type of base plate used apparently had little effect on the amount of porosity produced. In those few cases where there were appreciable differences in porosity from one type of base plate to another, it is believed that differences in weld metal composition rather than base plate deoxidation practice were responsible.

The porosity for welds made with the killed electrode ranged from zero to 15 holes per inch, and for every weld analyzed, the higher levels of porosity were associated with higher carbon contents in the weld metal.

Welds made with the semikilled electrode contained two to three times the number of gas cavities ordinarily present in the killed electrode welds. Since the gas contents of these two electrodes were virtually the same (Table 4), any difference in their behavior must be explained on the basis of residual deoxidizer content. Apparently, the combination of relatively high-carbon and low-silicon contents in the weld metal was responsible for a carbon monoxide reaction sufficiently intense to produce 13 to 23 holes per inch. It is important to note that even though the manganese content of the weld metal deposited with the semikilled electrode was quite high, it was not sufficient to prevent the carbon-oxygen reaction. This is in accord with the relative deoxidizing powers predicted in Fig. 9 for carbon and manganese at their respective weld metal concentrations.

Cross sections of a weld made with a semikilled electrode in Fig. 10 show that the bulk of the voids are lo-

cated along the fusion line in the "finger" region of the nugget. The upper half of Figs. 11, 12 and 13 show, respectively, the weld bead, a radiograph of the weld bead, and a longitudinal section through the weld bead at $^1/_{16}$ in. below the base plate surface, all for a weld laid with a semikilled electrode on a rimmed base plate.

Unlike the killed and semikilled electrodes, the rimmed electrode was sensitive to base plate deoxidation practice. The welds laid with a rimmed electrode on killed or semikilled base plate were in most cases comparable in porosity level to welds made with a semikilled electrode (see Fig. 14). However, whenever a weld was laid on *rimmed* steel base plate with the rimmed electrode, gross porosity resulted, both at 250 and 400 amp. Cross sections of two such highly porous welds are shown in Fig. 15. This type of uncountable porosity has been labeled "herringbone" porosity because of the pattern produced when the weld is radiographed. An example of the "herringbone" pattern can be seen in the lower half of Fig. 12 which is a radiograph of the rimmed-on-rimmed weld bead shown in the lower half of Fig. 11. Note that the streaks in the "herringbone" pattern of the radiograph were the result of the overlapping of hundreds of voids, as evident from the photograph of same weld after the upper part of the bead had been ground off (see lower half of Fig. 13).

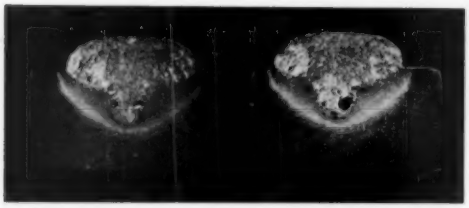

Fig. 10 Weld cross sections: Semikilled electrode on rimmed base plate ($^3/_4$ in. thick), welding grade argon, 400 amp, 5 ipm. 1 ×

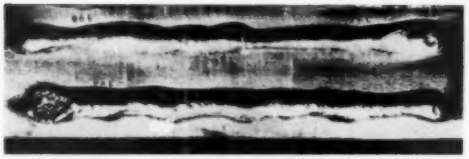

Fig. 11 Weld beads: Rimmed base plate ($^3/_4$ in. thick), welding grade argon, 400 amp, 10 ipm. Upper bead: Semikilled electrode. Lower bead: Rimmed electrode. 0.3 ×

Fig. 12 Radiograph of two weld beads in Fig. 11. Upper: Semikilled electrode (25 holes/1 inch). Lower: Rimmed electrode (Herringbone pattern). 0.7×

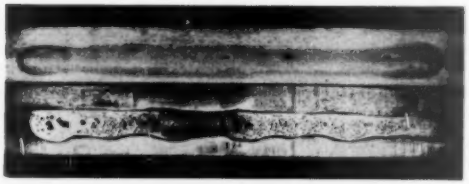

Fig. 13 Two weld beads of Fig. 11 after being ground flat. Upper: Semikilled electrode. Lower: Rimmed electrode. 0.3 ×

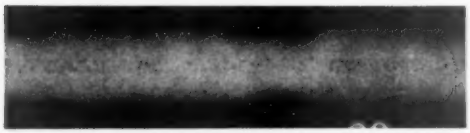

Fig. 14 Radiograph (22 holes/inch): Rimmed electrode on killed base plate ($^3/_4$ in. thick), welding grade argon, 400 amp, 10 ipm. 0.7 ×

The above results indicate that the quantity of deoxidizers present in the weld metal is quite critical in controlling the carbon monoxide reaction and hence the porosity.

Multipass Welding. The effect of multipass welding in welding grade argon with both Oxweld No. 32 (Lot No. 3) and Oxweld No. 43 was studied by laying three successive passes with each electrode in grooves $^1/_2$ in. wide by $^1/_2$ in. deep cut in $^3/_4$-in. thick base plate of

Table 13—Multipass Weld Study

All of the welds in this series were laid at approximately 400 amp, 10 ipm in grooves $^1/_2$ in. wide by $^1/_2$ in. deep cut in $^3/_4$-in. thick base plate of Steel BF. Welding grade argon was used

Welding electrode	*Number of pass*	*No. of holes/in. of weld* $D < {}^1/_{32}$ *in.*	$^1/_{32}$ *in.* $\leq D < {}^1/_{16}$ *in.*	$D \geq {}^1/_{16}$ *in.*	*Chemical Composition* % *C*	% *Mn*	% *Si*
Oxweld No. 32 (Lot No. 3)	First	6	0.6	0	0.21	0.89	0.14
	Second	7	0.6	0	0.18	0.96	0.15
	Third	15	0.9	0	0.17	0.98	0.19
					(Electrode 0.17	1.02	0.20)
Oxweld No. 43	First	18	8	0.7	0.12	0.41	0.038
	Second	12	5	2	0.077	0.29	0.012
	Third		Herringbone porosity		0.060	0.24	0.020
					(Electrode 0.051	0.20	0.020)

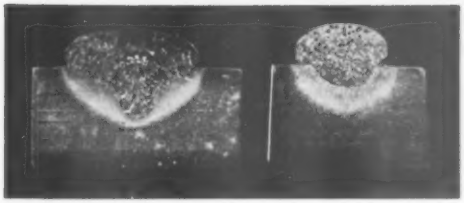

Fig. 15 Weld cross sections: Rimmed electrode on rimmed base plate (3/4 in. thick), welding grade argon. Left: 400 amp, 5 ipm. Right: 250 amp, 2 1/2 ipm. 1 ×

Steel BF. The weld bead was cleaned and radiographed after each pass in order to follow the changes in porosity. The results of this study, including chemical analyses of the weld metal from each pass, are reported in Table 13 while the cross sections of the two welds are shown in Fig. 16.

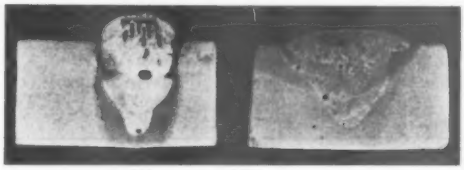

Fig. 16 Cross sections of multipass welds: Killed steel base plate (3/4 in. thick), welding grade argon: 400 amp, 10 ipm. Left: Rimmed electrode. Right: Killed electrode. 1 ×

The fairly large number of voids present in the first pass with the killed electrode may be due to the relatively high carbon content. The cross section of the weld nugget shows that the porosity in this pass is heavily concentrated along the fusion line. The second pass with the killed electrode resulted in no increase in porosity, but the third pass more than doubled the number of voids present. The sharp increase in the number of gas cavities with the third pass may be connected with an accumulation of dissolved or combined gases in the weld metal during the first two passes.

The effect of multipass welding on the formation of porosity was much more striking in the case of the rimmed electrode. The second pass produced a greater number of cavities larger than 1/16 in. in diameter, but the third pass produced a weld bead permeated with elongated voids in a "herringbone" pattern. A glance at the weld cross section and a check of the chemical analyses shows that the last pass with the rimmed electrode is practically all electrode metal with little or no dilution by the base plate (only a 0.04% manganese increase). As a result, the carbon-oxygen reaction proceeded unchecked to form gross porosity.

Effect of Ferromanganese Additions. Because the formation of "herringbone" porosity in welds made with a rimmed electrode on rimmed base plate seemed to be the result of insufficient residual deoxidizers, the effect of ferromanganese additions to this type of welds was studied. Four welds were laid in welding grade argon with Oxweld No. 43 in 1/2-in. wide by 1/4-in. deep grooves cut in 3/4-in. thick base plate of Steel H. Ferromanganese (0.70% C, 80.68% Mn, 6.81% Si and 11.8% Fe) in the form of −50 mesh powder was placed in the grooves prior to making three of the welds while none was added in the case of the fourth weld.

The weld made with no FeMn addition contained "herringbone" porosity; the other three welds had porosity varying from zero up to a total of five to ten holes per inch, depending upon how much of the powder was taken up by the weld metal. Thus, the addition of small quantities of deoxidizing elements to the weld metal by this method served to retard the carbon-oxygen reaction and greatly reduce the number of gas cavities.

V. *Effect of Welding Atmosphere on the Formation of Voids*

High Purity Argon. A number of welds were laid with killed electrode on killed base plate in high purity (99.99%) argon to determine if the small amounts of impurities present in the welding grade argon were responsible for the porosity observed in welds made with this gas. The results of this study, given in Table 14, were inconclusive. A decrease in porosity was obtained with the two welds made at 5 ipm, but there was no change in the porosity level for the two welds laid at 10 ipm.

It is evident from high-purity argon data included in Tables 11 and 12 that a change from the welding grade argon atmosphere to one of high-purity argon did not alter the heavy porosity observed in welds made with semikilled or rimmed electrodes.

Comparison of Helium and Argon. The porosity of two welds made with killed electrode on killed base plate in helium is compared in Table 15 with that present in two almost identical welds laid in welding grade

Table 14—High-Purity Argon Study

All of the welds in this series were made at approximately 400 amp on 3/4-in. thick base plate of Steel BF using Oxweld No. 32 (Lot No. 2)

Welding atmosphere	*Travel speed, ipm*	*No. of holes/in. of weld*		
		$D < 1/32$ *in.*	$1/32$ *in.* $\leq D < 1/16$ *in.*	$D \geq 1/16$ *in.*
99.99% argon	5	0.7	0.7	0.2
		0.6	0.3	0.2
Welding grade argon	5	5	1	0
		5	0.3	0
99.99% argon	10	0.6	0.4	0
		2	0	0
Welding grade argon	10	2	0.4	0
		1	0.1	0

Table 15—Comparison of Helium and Argon

The four welds in this series were made at 10 ipm on $^3/_4$-in. thick base plate of Steel BF using Oxweld No. 32 (Lot No. 3)

Welding atmosphere	*Average current, amp*	*Average voltage, v*	*Heat input, joules/in.*	*No. of holes/in. of weld* $D < {}^1/_{32}$ *in.*	$^1/_{32}$ *in.* $\leq D < {}^1/_{16}$ *in.*	$D \geq {}^1/_{16}$ *in.*
Helium	375	37.5	84,000	4	0.3	0
				4	0.5	0
Welding grade argon	375	33.5	75,000	3	1	0
				2	0.4	0

Table 16—Effect of Hydrogen in the Arc Atmosphere

All of the welds in this series were made on $^3/_4$-in. thick base plate of Steel BF or BC

Welding atmosphere	*Current level, amp*	*Travel speed, ipm*	*No. of holes/in. of weld* $D < {}^1/_{32}$ *in.*	$^1/_{32}$ *in.* $\leq D < {}^1/_{16}$ *in.*	$D \geq {}^1/_{16}$ *in.*
		Oxweld No. 32 (Lot No. 2)—Killed			
10% H_2 in high-purity argon	250	$7^1/_2$	0	0.1	0
10% H_2 in high-purity argon	400	10	4	0.8	0
			2	0.9	0
			5	0.6	0
10% H_2 in high-purity argon bubbled through water	400	10	4	0.5	0
100% H_2	200	10		Uncountable porosity	
		Oxweld No. 36—Semikilled			
10% H_2 in high-purity argon	250	10		Herringbone porosity	
	400	10		Herringbone porosity	
		Oxweld No. 43—Rimmed			
10% H_2 in high purity argon	250	10		Herringbone porosity	
	400	10		Herringbone porosity	

argon. There is no significant difference in the porosity levels of these welds.

Hydrogen. The effect of hydrogen in the arc atmosphere on the formation of porosity in welds made on killed or semikilled base plate is summarized for all three types of welding electrodes in Table 16. With killed electrode at either 250 or 400 amp, an addition of 10% hydrogen has caused no marked change in the number of voids present. However, with 100% hydrogen at 200 amp, the porosity consisted of uncountable clusters of moderate to large holes scattered throughout the weld. This confirms earlier experiments of Doan and Bounds[5] and indicates that hydrogen alone can cause porosity if its partial pressure is sufficiently high. A weld could not be sustained at the 400 amp level in an atmosphere of 100% hydrogen.

The semikilled and rimmed electrodes behaved quite differently from the killed in an atmosphere of 10% hydrogen in high-purity argon. At both 250 and 400 amp evidence of gross internal porosity was clearly visible on the surfaces of the beads. Escape of gases

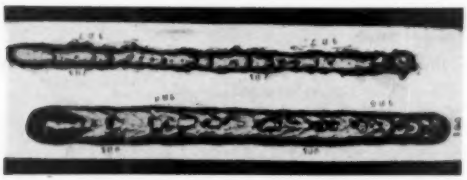

Fig. 17 Weld beads: Semikilled electrode on semikilled base plate ($^3/_4$ in. thick), 10% H_2 in high-purity argon. Upper bead: 250 amp, 10 ipm. Lower bead: 400 amp, 10 ipm. 0.3 ×

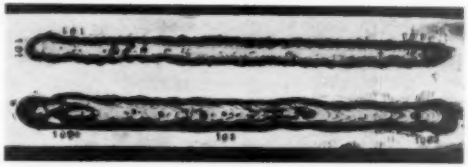

Fig. 18 Weld beads: Rimmed electrode on semikilled base plate ($^3/_4$ in. thick), 10% H_2 in high-purity argon. Upper bead: 250 amp, 10 ipm. Lower bead: 400 amp, 10 ipm. 0.3 ×

during welding resulted in the formation of transverse slits and open voids in the top of the deposits (see Figs. 17 and 18). During welding at 400 amp, the molten weld metal billowed up behind the arc until it was almost even with the end of the copper guide tube, as evidenced by the swelled portion of the weld bead still intact at the crater. Radiographs of all four welds, shown in Figs. 19 and 20, revealed a "herringbone" pattern of porosity. The large number of cavities in the "finger" region of the 400-amp weld deposits is clearly visible along the center lines of these radiographs.

All of the evidence points to an extremely strong evolution of gas during welding. Such evolution could be the result of either of two factors: (1) the hydrogen, after dissolution in the weld metal, may have diffused into gas bubbles formed by the carbon monoxide reaction, which is known to be quite active in welds made with either the semikilled or rimmed electrode, or (2) the hydrogen itself may have reacted with the oxygen in

Table 17—Effect of Nitrogen in the Arc Atmosphere

All of the welds in this series were made on 1/4-in. thick base plate of steel BF

Welding atmosphere	*Current level, amp*	*Travel speed, ipm*	*No. of holes/in. of weld* $D \leq 1/32$ *in.*	$1/32$ *in.* $< D < 1/16$ *in.*	$D \geq 1/16$ *in.*
Oxweld No. 32 (Lots No. 2 and No. 3)—Killed					
9.2% N_2 in high-purity argon	250	7 1/2	0 9	0	0
9.2% N_2 in high-purity argon	400	10	4	1	0
			5	1	0
			4	2	0
9.2% N_2 in high-purity argon bubbled through water	400	10	7	2	0
			4	2	0
20% N_2–80% welding grade argon	400	10	8	2	0
40% N_2–60% welding grade argon	400	10	Herringbone porosity		
100% N_2	250	7 1/2	Saturated with voids. Huge surface cavities		
100% N_2	400	10	Saturated with voids. Huge surface cavities		
Oxweld No. 43—Rimmed					
9.2% N_2 in high-purity argon	400	10	Herringbone porosity		

the weld metal to form water vapor. On the basis of data to be presented later in connection with studies on oxide scale, it is believed that the first mechanism is probably responsible for the highly porous beads that were obtained.

Nitrogen. The results of welding with killed and rimmed electrodes in atmospheres containing from 9.2 to 100% nitrogen are given in Table 17. The usual porosity level for welds made with a killed electrode on killed base plate was not increased by the addition of 9.2% nitrogen to the welding atmosphere. While the number of voids remained about the same with 20% nitrogen present in the arc atmosphere, the porosity was no longer confined to the center line of the weld ("finger" region) but was scattered throughout. At 400 amp in either a 40 or 100% nitrogen atmosphere, the molten weld metal billowed up high around the arc resulting in a solidified shell almost 1 in. high at the crater. Pinholes were visible in the surface of the weld bead made in the 40% nitrogen atmosphere, and large surface cavities were exposed in the deposits laid in 100% nitrogen (see Fig. 21). The porosity patterns for the latter welds are shown in the radiographs of Fig. 22.

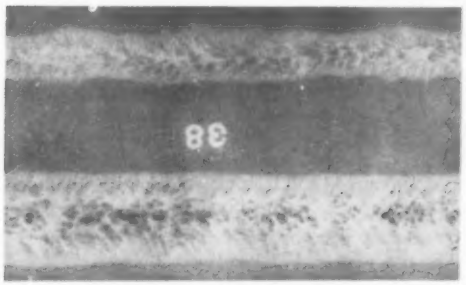

Fig. 19 Radiograph of two weld beads in Fig. 17. Upper: 250 amp, 10 ipm (Herringbone pattern). Lower: 400 amp, 10 ipm (Herringbone pattern). 0.7 ×

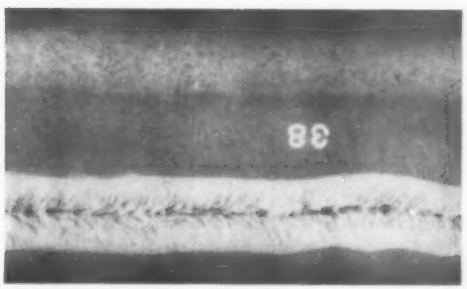

Fig. 20. Radiograph of two weld beads in Fig. 18. Upper: 250 amp, 10 ipm (Herringbone pattern). Lower: 400 amp, 10 ipm (Herringbone pattern). 0.7 ×

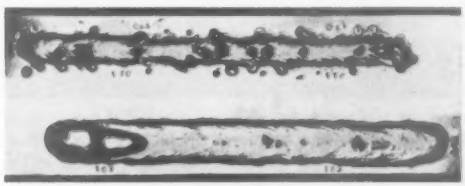

Fig. 21 Weld beads: Killed electrode on killed base plate (3/4 in. thick), 100% N_2. Upper bead: 250 amp, 7 1/2 ipm. Lower bead: 400 amp, 10 ipm. 0.3 ×

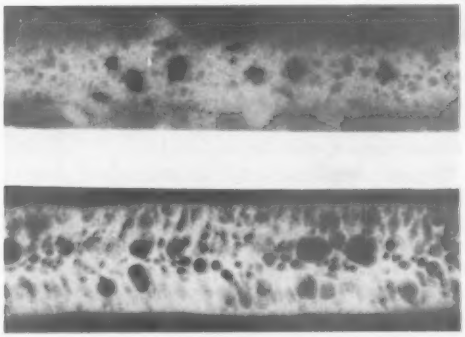

Fig. 22 Radiograph of two weld beads in Fig. 21. Upper: 250 amp, 7 1/2 ipm (uncountable porosity). Lower: 400 amp, 10 ipm (uncountable porosity). 0.7 ×

Table 18—Effect of Oxygen in the Arc Atmosphere

All of the welds in this series were made on $^3/_4$-in. thick base plate of Steel BF

Welding atmosphere	*Current level, amp*	*Travel speed, ipm*	*No. of holes/in. of weld* $D < {}^1/_{32}$ *in.*	${}^1/_{32}$ *in* $\leq D <$ ${}^1/_{16}$ *in.*	$D \geq {}^1/_{16}$ *in.*
		Oxweld No. 32 (Lot No. 2)			
1% O_2–99% welding grade argon	400	10	4	0.3	0
			3	1	0
5% O_2–95% welding grade argon	400	10	2	1	0
			2	0.5	0
10% O_2 in high-purity argon	400	10	11	3	0.4
			11	4	0.3
10% O_2 in high-purity argon	250	$7^1/_2$	2	1	0
		Oxweld No. 32 (Lot No. 3)			
1% O_2–99% welding grade argon	400	10	0.8	0	0
10% O_2 in high-purity argon	250	$7^1/_2$	1	0.1	0
10% O_2 in high-purity argon	400	10	0.6	0	0
10% O_2–90% welding grade argon	400	10	0.1	0	0
15% O_2–85% welding grade argon	400	10	0.3	0.1	0
20% O_2–80% welding grade argon	400	10	0.8	1	0

The production of heavily porous weld beads in the atmospheres containing more than 20% nitrogen was probably the result of the increased solubility of nitrogen in the molten weld metal with the increased partial pressure of nitrogen in the arc atmosphere coupled with the sharp decrease in solubility upon cooling and solidification. These results bear out Fast's contention[6] that nitrogen can play an important role in the formation of porosity in welds laid with bare rods in air. The percentage of nitrogen at which the weld bead becomes completely unsound may depend, in part, upon the capacity of the weld metal to tie up the nitrogen with alloying elements.

The weld made with the rimmed electrode in a 9.2% nitrogen in high-purity argon atmosphere behaved similarly to the weld made with the killed electrode in 40% nitrogen: the molten weld metal billowed high behind the arc and the bead was only a shell at the crater. It is believed that the gross porosity in this deposit was caused by the diffusion of nitrogen dissolved in the molten weld metal into gas bubbles formed by the carbon-oxygen reaction and having a zero partial pressure of nitrogen. As seen earlier, this mechanism may also apply to the behavior of hydrogen in the arc atmosphere. Both the more active carbon-oxygen reaction and the absence of residual deoxidizers were probably responsible for the fact that the break in porosity level occurred at a lower percentage of nitrogen for the rimmed electrode than for the killed.

Oxygen. Additions to the arc atmosphere of up to 20% oxygen were studied. Because the effect of this gas on the formation of porosity was different for the two lots of Oxweld No. 32 used, the results given in Table 18 have been listed separately for each lot of electrode. In atmospheres containing up to 15% oxygen, Lot No. 3 produced welds containing fewer voids than were generally present in welds made in argon with this electrode. For Lot No. 2 of Oxweld No. 32, additions of 1–5% oxygen did not change the usual level of porosity. However at 400 amp, additions of 10% oxygen raised the porosity to a level comparable to that of welds made with a semikilled electrode (13–23 holes/inch). The majority of the voids in these welds were confined to the "finger" region of the weld bead. The porosity at 250 amp for Lot No. 2 was also greater than that generally observed in argon and was scattered throughout the weld.

The apparent reason for the increase in the number of voids with increased oxygen in the arc atmosphere for Lot No. 2 was that the oxygen depleted the reserve of deoxidizing elements in the weld to a point where it was free to react with carbon to produce carbon monoxide. A comparison in Table 19 of the actual chemical composition of the weld metal with that calculated on the basis of electrode and base plate composition and percentage dilution of the weld indicates that such a depletion of residual deoxidizers actually occurred. Although there are no real differences in the C, Mn and Si contents for the two lots of killed electrode, the porosity results suggest that Lot No. 3 has a much greater capacity for deoxidation than Lot No. 2.

Table 19—Comparison of Actual and Calculated Compositions of Welds Made in an Atmosphere of 10% O_2 in High-Purity Argon with Oxweld No. 32 (Lot No. 2)

Welding conditions		*Composition of weld metal, %* C	Mn	Si
250 amp, $7^1/_2$ ipm	Calculated	0.16	0.93	0.16
	Actual	0.13	0.43	0.02
400 amp, 10 ipm	Calculated	0.16	0.92	0.16
	Actual	0.16	0.79	0.09

Water Vapor. The effect of water vapor in the arc atmosphere on the soundness of welds made with either killed or rimmed electrodes is shown in Table 20. While the presence of water vapor did not increase the amount of porosity in welds made with the killed electrode, it resulted in the formation of "herringbone" porosity in the weld laid with the rimmed electrode.

Table 20—Effect of Water Vapor in the Arc Atmosphere

All of the welds in this series were made on $^3/_4$-in. thick base plate of Steel BF in an atmosphere of welding grade argon which had been bubbled through water at room temperature and at atmospheric pressure

Welding electrode	*Current level, amp*	*Travel speed, ipm*	*No. of holes/in. of weld*		
			$D < {}^1/_{32}$ *in.*	$^1/_{32}$ *in.* $\leq D < {}^1/_{16}$ *in.*	$D \geq {}^1/_{16}$ *in.*
Oxweld No. 32 (Lot No. 2)	250	$7^1/_2$	0	0	0
			0	0	0
Oxweld No. 32	400	10	4	1	0
			2	1	0
Oxweld No. 43	400	10	Herringbone porosity		

As in the case of welds made with the semikilled or rimmed electrode in a 10% hydrogen atmosphere, the gross porosity was probably caused by the diffusion of hydrogen into gas bubbles formed by the carbon-oxygen reaction or perhaps by the reaction of hydrogen itself with oxygen in the weld metal. The hydrogen, in this case, was supplied by the dissociation of water vapor in the arc or by the reaction of water vapor with the molten weld metal ($Fe + H_2O \leftrightarrows FeO + 2H$).

Included in Tables 16 and 17 are welds made with killed electrode in 10% hydrogen and 10% nitrogen atmospheres, both of which had been bubbled through water prior to entering the welding chamber. The porosity counts for these welds show that the water vapor had no "triggering" action on the formation of voids by either hydrogen or nitrogen.

VI. Influence of Surface Contaminants on the Formation of Porosity

Effect of Oxide Scale. The results in Table 21 show that a marked difference in porosity was obtained when killed and rimmed electrodes were used to lay welds in argon on killed base plate having a natural coating of rust and mill scale. While the number of voids produced by the killed electrode was more than doubled by the presence of the oxide coating, the coating had little effect on the porosity of welds laid with the rimmed electrode. The majority of the voids in the killed electrode welds were located in the "finger" region, which was accentuated by the oxide scale. The smaller amount of porosity in the welds with the rimmed electrode could be due to the much lower carbon content of the weld metal or possibly to the shallower and more regular weld nugget produced (see Fig. 23).

In an attempt to produce an active water vapor reaction ($2H + O \leftrightarrows H_2O$), an atmosphere of 10% hydrogen in high-purity argon was used to make two welds on the oxidized base plate with the killed electrode.

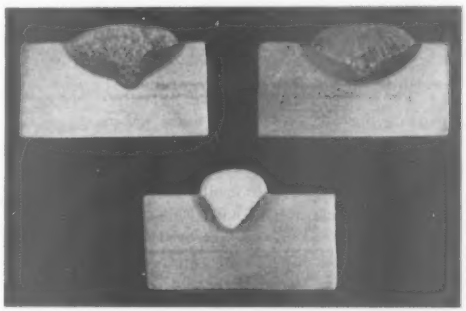

Fig. 23 Cross sections of welds made on oxide covered surface of killed base plate ($^3/_4$ in. thick), 400 amp, 10 ipm. Upper left: Killed electrode in welding grade argon. Upper right: Killed electrode in 10% H_2–90% high-purity argon. Bottom: Rimmed electrode in welding grade argon. 1 ×

Table 21—Effect of Oxide Scale

All of the welds in this series were made at approximately 400 amp, 10 ipm on $^3/_4$-in. thick base plate of Steel BF. The base plate surface was covered with a natural mixture of iron rust and mill scale about $^1/_{32}$ in. thick

Welding electrode	*Welding atmosphere*	*No. of holes/in. of weld*			*Composition of weld metal, %*		
		$D < {}^1/_{32}$ *in.*	$^1/_{32}$ *in.* $\leq D < {}^1/_{16}$ *in.*	$D \geq {}^1/_{16}$ *in.*	*C*	*Mn*	*Si*
Oxweld No. 32 (Lot No. 3)	Welding grade argon	10	10	0.3			
		11	10	0.8			
		7	9	0.6	0.15	0.94	0.14
		9	8	0.4	0.18	0.92	0.13
Oxweld No. 32 (Lot No. 3)	10% H_2 in high-purity argon	0.5	0.6	0			
		2	0.3	0	0.14	0.95	0.15
Oxweld No. 43	Welding grade argon	3	0.6	0			
		0.5	0.3	0	0.11	0.45	0.03

		Weld dimensions			
		Width of nugget, in.	*Depth of penetration, in.*	*Nugget area, sq in.*	*Area of penetration, sq in.*
Oxweld No. 32 (Lot No. 3)	Welding grade argon	0.82	0.34	0.24	0.13
Oxweld No. 32 (Lot No. 3)	10% H_2 in high-purity argon	0.83	0.27	0.22	0.12
Oxweld No. 43	Welding grade argon	0.56	0.27	0.17	0.084

Surprisingly enough, the porosity was greatly reduced even though both oxygen and hydrogen were present in the weld metal. While the use of hydrogen has decreased the depth of penetration and almost eliminated the sharp "finger" of the nugget (see Fig. 23), it is not certain that these factors alone are responsible for the large improvement in weld metal soundness. It is quite possible that the hydrogen effectively deoxidized the weld metal via the water vapor reaction without producing any porosity. Such a water vapor reaction could have occurred sufficiently early in the welding cycle to allow for the escape of the gaseous reaction products.

CONCLUSIONS

The following conclusions may be drawn from the investigation reported here:

1. Porosity increased with increasing current density.

2. Travel speeds from $2^5/_8$ to 15 ipm had no effect on porosity. At $19^1/_2$ ipm mechanical porosity (irregular voids) appeared.

3. Except where extremely heavy porosity was present, the majority of the voids were located either along or near the fusion line or in the "finger" region of the weld.

4. The carbon-oxygen reaction appeared to be active in causing porosity. Porosity increased as the carbon content of the weld metal increased, but decreased with increased silicon or manganese content.

5. Semikilled electrode produced two to three times the porosity encountered with killed electrode on all base plates.

6. With killed or semikilled electrode, porosity was unaffected by variations in base plate deoxidation, while with rimmed electrode, the porosity increased sharply as the base plate was changed from killed to rimmed quality.

7. Rimmed electrode on rimmed plate produced a gross porosity having a herringbone pattern when radiographed. Ferromanganese additions reduced this porosity to approximately that obtained with killed electrode.

8. In multipass welds with rimmed electrode on killed plate, the third pass weld showed gross porosity in a herringbone pattern.

9. Additions of 10% hydrogen or nitrogen to the arc atmosphere did not change the degree of porosity in welds with killed electrode on killed plate. With rimmed electrode, these additions caused gross porosity. 100% hydrogen, or 40 to 100% nitrogen produced gross porosity with the killed electrode.

10. The effects of oxygen additions appeared to be sensitive to the lot of killed electrode used. With one lot, additions up to 20% actually decreased the porosity somewhat. With another lot, additions over 5% raised the porosity.

11. Water vapor in the arc atmosphere was inactive with killed electrode, but caused gross porosity with rimmed electrode.

12. Oxide scale on killed plate welded with killed electrode doubled or tripled the porosity. By adding 10% hydrogen to the atmosphere, porosity was restored to normal. The oxide coating had no effect on the porosity level obtained with rimmed electrode.

ACKNOWLEDGMENTS

This investigation was made possible by the grant of a fellowship in metallurgical engineering by E. I. du Pont de Nemours and Co., Inc. The authors gratefully acknowledge the assistance of Glenn W. Oyler, graduate student at Lehigh University, in a large part of the experimental work. Appreciation is expressed to the Union Carbide and Carbon Corp. for the supply of much of the materials and equipment used in this study.

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The Continuous Cooling Transformation of Weld Heat-Affected Zones

* *A novel method is described for studying the continuous cooling transformations that occur in the heat-affected zone of weldments. The significance of the mode and type of transformation is discussed*

by W. R. Apblett, L. K. Poole and W. S. Pellini

Abstract

A novel method is described for studying the continuous cooling transformations that occur in the heat-affected zone of weldments. A tapered section bar of small diameter through which a heavy controlled current is passed to cause rapid heating and melting at the least section is used to simulate the heat-affected zone of a weld. Almost exact correspondence between the weld thermal cycles and those of the taper bar specimen is obtained. A number of these specimens are quenched after fusion at such times as are required to determine metallographically the beginning and end of transformation. A Time-Temperature-Transformation diagram was constructed for a high-tensile steel (HTS) heat-affected zone.

Three distinctly different types of transformation were noted: (1) transformation from homogeneous austenite regions which comprise the portion of the heat-affected zone nearest the line of fusion; (2) transformation from heterogeneous austenite regions (those regions of the heat-affected zone heated in the range of 1700–1900° F); (3) transformation from an austenite (high carbon) plus untransformed ferrite field.

INTRODUCTION

THE present-day trend to larger and more highly stressed structures had led to the development of notch-tough, high-strength steels. Within certain limits, the analyses of such steels can be customized according to well-established procedures to produce desired properties in specific ranges of thickness and for specific commercial heat treatments. Such rational customizing of analyses, which is now widely used in place of empirical formulation, was not possible prior to the establishment of the basic scientific principles which govern the transformations of steels. The application of these same principles to the problem of customizing for transformations in the HAZ of welds has met with limited success. It is recognized that, while the basic principles of classical transformation and hardenability concepts apply, certain extensions of knowledge are required to permit precise evaluation of welding transformation. With such extensions of information it should be possible to relate chemical analysis to transformational behavior in welding, which is the essence of the welding hardenability problem.

The present time-temperature-transformation curves for steels are based on the transformations from homogeneous austenites which is not the case for the transformations of the HAZ of welds. Thus, the extensions of information which are needed concern the problem of the transformational features of the various partially austenitized and partially homogenized regions of the weld HAZ.

Various investigations have shown that the mode of the transformations of steels is affected by such factors as rate of formation of austenite, austenite grain size, the degree of homogeneity of the austenite, the degree of solid solution of the alloying elements and the rate of nucleation and growth of the various transformation products.[1–4] Inasmuch as these factors are time and temperature dependent, the hardenability factors derived cannot be applied directly to welding. In addition the transformations during welding are all of a continuous cooling nature which are not taken into account in the conventional TTT diagrams. The complexity of the interplay of these various time-dependent variables is such that an attempt to study these factors under the variety of conditions pertinent to welding, using conventional methods, would require an investigation of such magnitude to make it impractical.

A step in the direction of solving the problem of continuous cooling transformation has been reported by Liedholm.[5] The method entails the determination of a continuous cooling transformation diagram; however, this method *per se* is not directly applicable

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to the welding problem since it is based on the transformation from homogeneous austenites which are not achieved in the greater portion of the heat-affected zone during the short times involved in the welding process.

The development of a new method of approach specific to the conditions of welding was required for weld transformation studies. The practical difficulties of arresting transformation for metallographic studies or otherwise following transformation by property changes on an actual weldment suggested the use of a weld synthetic specimen simulating the variations of time, temperature, heating rates and cooling rates which occur in weld heat-affected zones.

The purpose of this investigation was, therefore, to develop such a method and to show its application to the construction of a continuous cooling time-temperature-transformation diagram for a typical weld heat-affected zone.

MATERIAL

The material used in this investigation was produced to meet Navy Specification 48S5g, Manganese High-Tensile Steel (HTS) of the following analysis:

C, %	0.15
Mn, %	1.12
Si, %	0.35
Cu, %	0.16
Ni, %	0.18
Cr, %	0.15
Mo, %	0.02
V, %	0.033
Ti, %	0.01

MEASUREMENT OF WELD THERMAL CYCLES

As a first step in developing a weld synthetic specimen it was necessary to determine the thermal cycles developed in the HAZ of a practical weld. The metallographic structures associated with specific thermal cycles developed at various positions in the HAZ were also required for subsequent comparison with the structures developed in the specimen simulating the weld HAZ.

Choice of Welding Conditions

Previous work conducted by Hess, *et al.*[6] has indicated that simple bead-on-plate welds represent the conditions of the top pass of practical butt welds. Inasmuch as the transformation products resulting from the last thermal cycle are not modified it is generally accepted that the equivalent bead-on-plate HAZ represents the quality of the weld zone at the critical weld toe positions of butt welds. It was therefore decided that a simple bead-on-plate weld would provide a realistic thermal condition for a transformation study. The bead-on-plate welds were made on a test plate prepared by machining the project steel to finished dimensions of 6 x 12 x 1 1/4 in. The welds were made with automatic arc-welding equipment using 3/16-in. E6016 electrode. The measurement of the welding conditions was accomplished by measuring the arc current and voltage by recording meters. The arc travel speed was maintained constant by a motor-driven carriage. The welding conditions selected were 175 amp, 26 v and 6 ipm arc travel speed, which correspond to an energy input of 45,500 joules/inch.

Thermocouple Technique

A series of eight 0.054-in. diam holes on 1/4-in. centers are drilled along the major center line of the 6 x 12-in. plate. The first hole is drilled to 1/8 in. of the surface of the plate and each succeeding hole is made an additional 1/32 in. from the surface. Thermocouples constructed of 4-in. lengths of 28-gage chromel-alumel thermocouple wire are insulated by dipping in a refractory cement and then flash welded into the bottom of these holes. The ends of the thermocouples are inserted into small tubes of mercury that are held in an aluminum block located directly beneath the plate that is to be welded. The aluminum block serves to maintain a constant cold junction temperature during the test run. A photograph of the test plate ready for welding is shown in Fig. 1. A 6-ft length of shielded cable containing two 14-gage copper wires completes the circuit between each thermocouple and the temperature measuring equipment.

TEMPERATURE MEASUREMENT

The measurement of the rapid thermal changes which occur in the heat-affected zone of a weld requires instrumentation capable of very rapid response. It is also desirable that the thermal changes which occur at various distances from the fusion line be measured

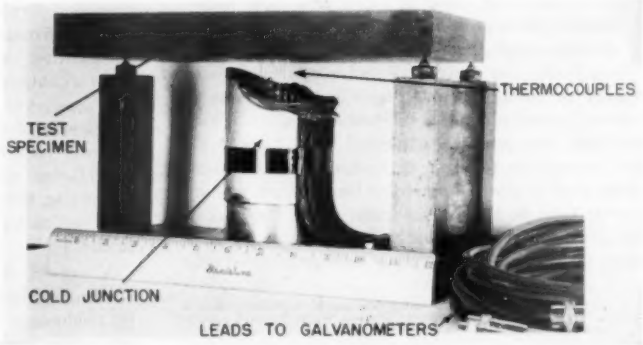

Fig. 1 Setup for obtaining weld thermal cycles

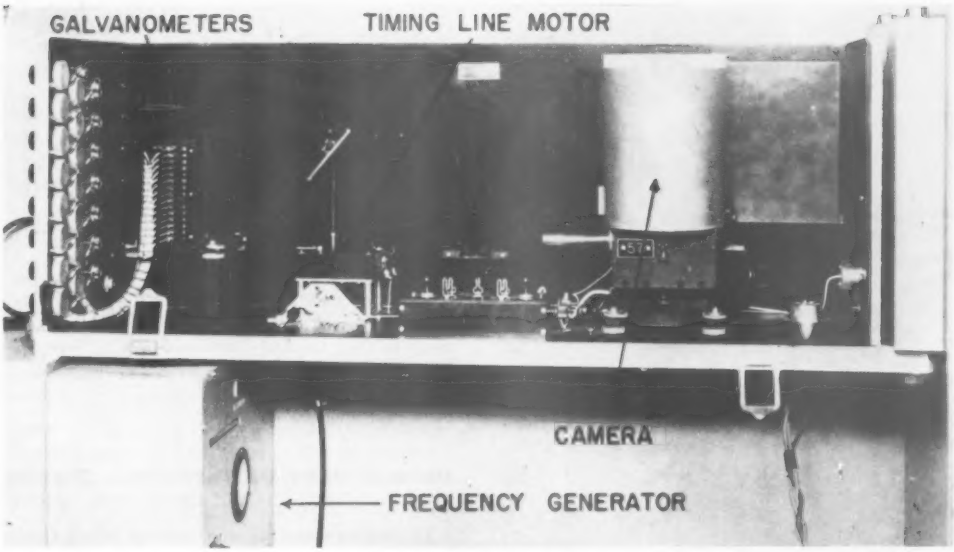

Fig. 2 High-speed recorder

simultaneously on a single weld. An instrument capable of satisfying these requirements is shown in Fig. 2. Basically the instrument consists of a number of small, low-inertia, moving-coil galvanometers, each mounting a small mirror which reflects a light spot from a lamp source onto rapidly moving photographic paper. Superimposed on these light spots is a timing line obtained by cutting a light source by a slotted drum driven by a synchronous motor. The speed of this motor is accurately controlled by means of an amplifier circuit driven by a precise tuning fork.

The galvanometers are calibrated by feeding in a number of known millivoltages of the order of the thermocouple output. The deflection of each of the galvanometers is photographically recorded; this record is then translated in terms of deflection versus temperature (millivoltage) to give the desired calibration curve.

The method of obtaining the time-temperature relation for the various thermocouple locations is the reverse of that discussed previously for calibration of the temperature-measuring equipment. Measurements are made of the deflection of each of the galvanometers at 1-sec intervals (0.1-sec interval near the peak temperature).

The bead-on-plate weld is then cut longitudinally to bare the holes drilled to accommodate the thermocouples. Measurements of the exact depth of each hole and its distance from the fusion line are obtained by use of a traveling microscope. The specimen is then polished and photomicrographs of the structure at the tip of each thermocouple are taken. Thus, the structures associated with a number of experimentally determined thermal cycles are available.

DEVELOPMENT OF THE SPECIMEN SIMULATING THE WELD HEAT-AFFECTED ZONE

Having obtained the weld thermal data for the indicated welding conditions the objective was then to design a weld synthetic specimen which would produce an expanded HAZ (for ease of metallographic study) with heating and cooling curves which quantitatively match those of the actual weld HAZ. Such a specimen

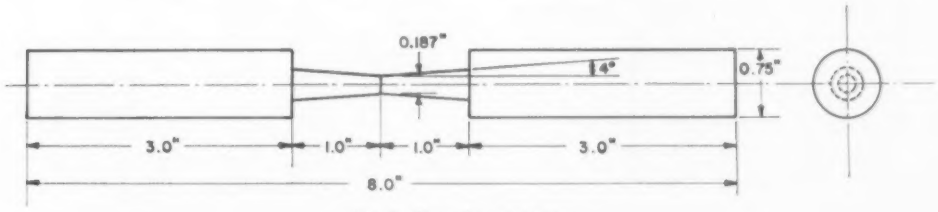

Fig. 3 Taper bar specimen

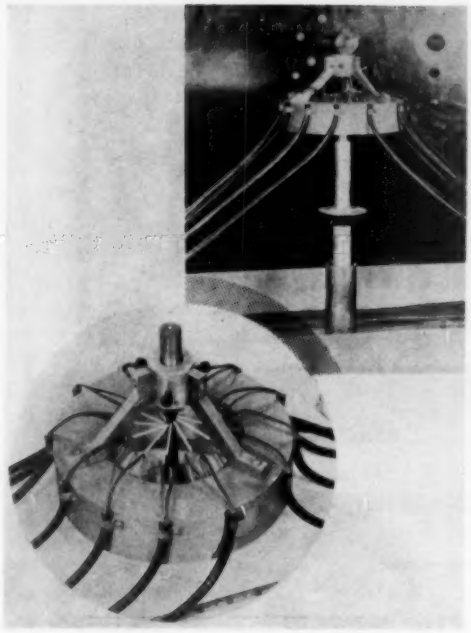

Fig. 4 Setup for obtaining taper bar thermal curves

must match (1) austenitizing time, (2) maximum temperature attained and (3) cooling rates. The specimen evolved is essentially a tapered section bar of small diameter through which a heavy controlled current is passed to cause rapid heating and melting at the least section. By proper choice of specimen design and current imput, the heating and cooling rates may be controlled over wide ranges. Axial heat flow back along the length of the bar during the cooling cycle, which simulates the mass quench of the unheated regions of a weldment, was ensured by the use of heavy butt ends. Thus, the short-time high-temperature conditions of welding may be simulated in all respects. The design and dimensions of the specimen used in this investigation are shown in Fig. 3. The design was arrived at empirically by determination of the thermal conditions developed as the result of systematic variations of the various dimensions. A wide range of weld thermal conditions may be reproduced by adjustment of the various critical dimensions of the specimen. Hereafter this specimen will be referred to as the taper-bar specimen.

MEASUREMENT OF TAPER BAR THERMAL CYCLES

The measurement of the thermal changes which occur in the taper bar during heating and subsequent cooling were made using the same temperature-recording equipment as was used in obtaining the weld thermal cycles. The bar was circumferentially scribed with lines that were accurately spaced at 0.0625-in. increments, the first line being 0.0625 in from the least section of the bar. Thermocouples constructed of 28-gage chromel-alumel wire were prepared as previously described and flash welded to the bottom of small (0.028 in. diam by 0.020 in. deep) holes drilled at each of the scribed positions. The couples were arranged heli-

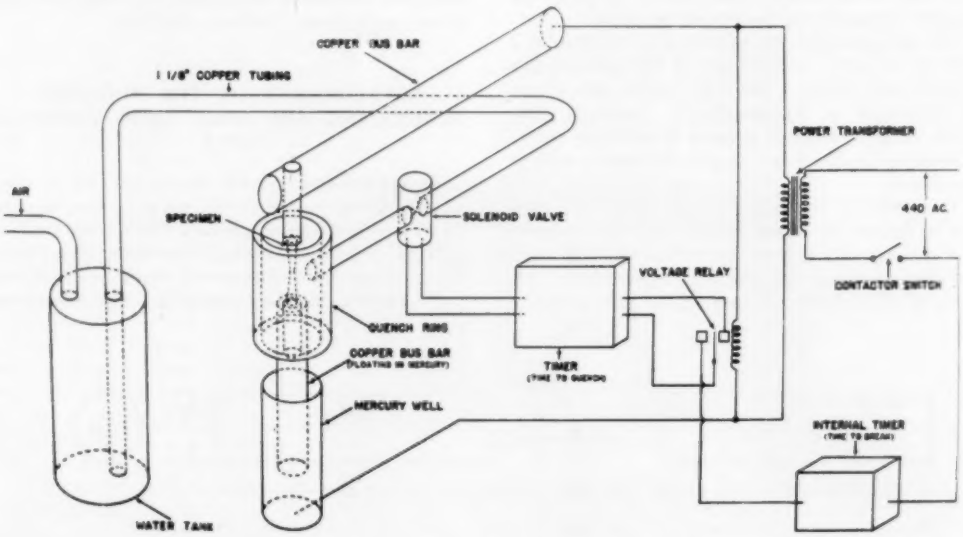

Fig. 5 Schematic drawing of taper bar equipment

cally around the bar. Each couple was provided with a mercury well cold junction which was kept at room temperature by insertion in an annular aluminum block. The experimental setup for obtaining the taper bar thermal cycles is shown in Fig. 4.

Figure 5 presents a schematic drawing of the complete equipment. The quenching sleeve (purpose to be described) is replaced by the annular ring section when conducting thermal studies. The power source is a 1200-ampere welding transformer utilizing a primary contactor. A unique feature of this equipment is the use of a mercury well which not only carries the necessarily high amperage but also serves as a means of reducing the load on the specimen to a small value and also eliminates any bending forces. This is accomplished by floating in mercury the copper bus bar which is to be attached to the specimen. The mercury level is adjusted so that a small tensile load remains to cause the lower half of the specimen to drop away once the central section has melted. For the specimens herein described a current of 850 amp causes melting of the least section in approximately 7 sec—free cooling follows. After the thermal data are obtained the bar is then sectioned longitudinally and polished for metallographic examination of the structures at each of the thermocouple locations.

COMPARISON OF THE WELD AND TAPER BAR THERMAL CYCLES AND ASSOCIATED MICROSTRUCTURES

The experimentally determined thermal cycles at various positions are shown in Figs. 6 and 7. The figures near the peak temperature of each of the curves represent the distance from the fusion line and the smallest reduced section of the taper bar, respectively. The curves agree well although there is a tendency for the weld curves to remain near their peak temperatures for slightly longer periods of time. Similar studies made on higher energy input welds have indicated that this condition becomes more pronounced as the energy input is increased. This is due to the fact that the electrode is supplying heat to any one specific location as it approaches, passes over and moves away from the location, whereas in the taper bar the source of heat is essentially a stationary point (the molten pool) after separation.

It was noted that when the log of the maximum temperature reached at each thermocouple location was plotted against its respective distance from the fusion line, or the smallest reduced section of the taper bar, a straight line plot resulted at temperatures above the lower critical temperature. Plots of this type for the weld and the taper bar are shown in Fig. 8. The fusion line in the taper bar has been determined metallographically and this point is indicated on the upper curve. It is interesting to note that this checks the solidus temperature of a 0.15 C steel. With these plots it is possible to pick any desired temperature and to determine its distance from the fusion line either in the weld heat-affected zone or in the taper bar. These respective positions represent points of equivalent

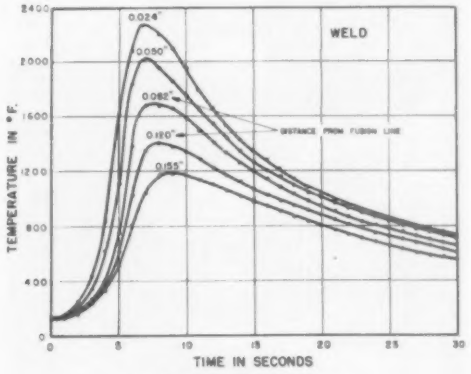

Fig. 6 Weld thermal curves

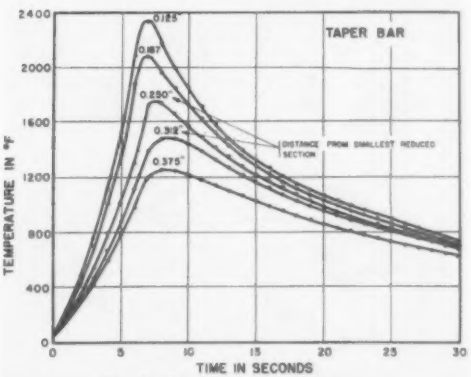

Fig. 7 Taper bar thermal curves

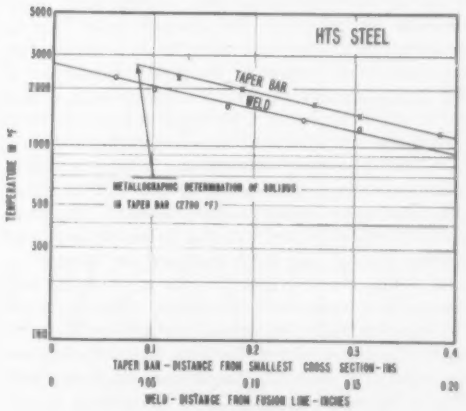

Fig. 8 Semilog peak temperature plots

thermal history. By using this system it is possible to take photomicrographs of the positions of the taper bar which exactly correspond to any selected position of the weld HAZ. Figure 9 depicts corresponding microstructures of the weld HAZ and the air-cooled taper bar HAZ which were taken at locations of corresponding maximum temperature determined by this method.

The comparisons between the thermal cycles and the microstructures show that the taper bar synthesizes the weld HAZ with the exception that the length of the heat-affected portion of the taper bar has been purposely expanded to make metallographic transformation studies easier.

In Fig. 10 are presented photomacrographs of the cross section of the weld and taper bar. It is interesting to note that the line of demarcation between the HAZ and the unaffected base metal of the taper bar is straight and normal to the longitudinal axis of the bar thus indicating uniform cross-sectional heating and cooling conditions. To check this observation a small hole (0.028 in.) was drilled completely through the specimen at $^1/_4$ in. from the reduced section. Thermocouples were then flash welded near the surface and at the center of the cross section. Comparison of the data substantiated the fact that the cross-sectional heating and cooling was uniform.

CONSTRUCTION OF THE CONTINUOUS COOLING TRANSFORMATION DIAGRAM

It has been shown that the taper bar synthesizes the weld HAZ; therefore, all that is required to produce a continuous cooling transformation diagram for the subject welding conditions is to quench taper bar specimens after fusion at such times as are required to metallographically determine the progress of transformation. Quenching is accomplished by means of a spray attachment completely surrounding the specimen as shown in Fig. 11. Water at room temperature is fed to this attachment from a surge tank under constant air pressure. The quench delay time is controlled by an electronic timer which is triggered by the open-circuit voltage of the power transformer at the instant the bar breaks. The functioning of each bar tested is checked by a control thermocouple which is located at one of the locations where the thermal cycles have been previously determined. A total of twenty specimens are heated, fused and quenched at time intervals differing by approximately 1 second. The structural changes associated with the various cooling cycles existing through the HAZ therefore are "frozen" at various time intervals from the time at which the peak austenitizing temperature is reached. Figure 12 shows the experimentally determined thermal cycles (0.187 in. from reduced section) for three separate specimens quenched at 3, 5 and 12.6 sec after the bar had melted. Due to the relatively small size of the section, quench rates in excess of 1000° F/sec are attained. The specimens are then sectioned and examined metallographically to determine the progression of transformation.

Figure 13 presents a series of photomicrographs illustrating the progress of transformation of a particular section of the taper bar that reached a peak tempera-

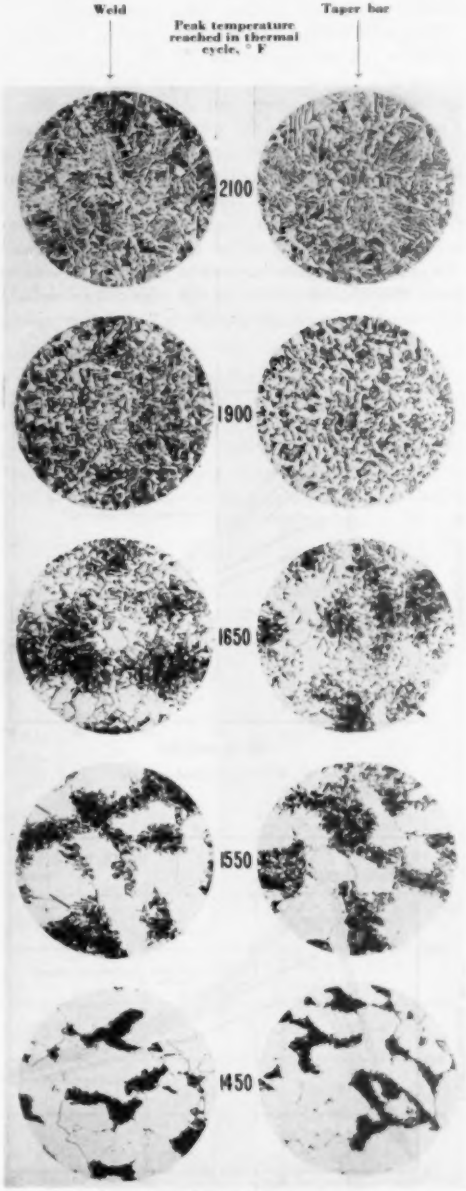

Fig. 9 Weld and taper bar microstructures at same peak temperatures

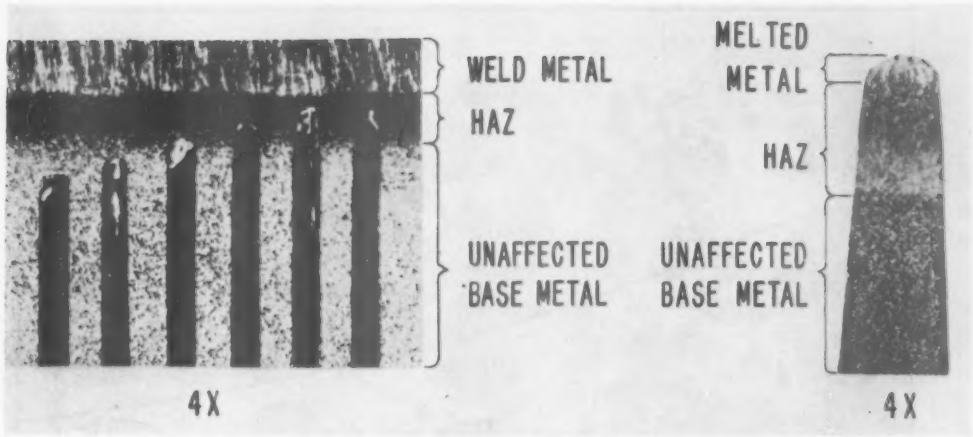

Fig. 10 Macros of weld and taper bar HAZ

ture of 1450° F. In Fig. 14 is shown the continuous cooling transformation diagram constructed by similar metallographic examination of various positions covering the entire simulated HAZ of the taper bar.

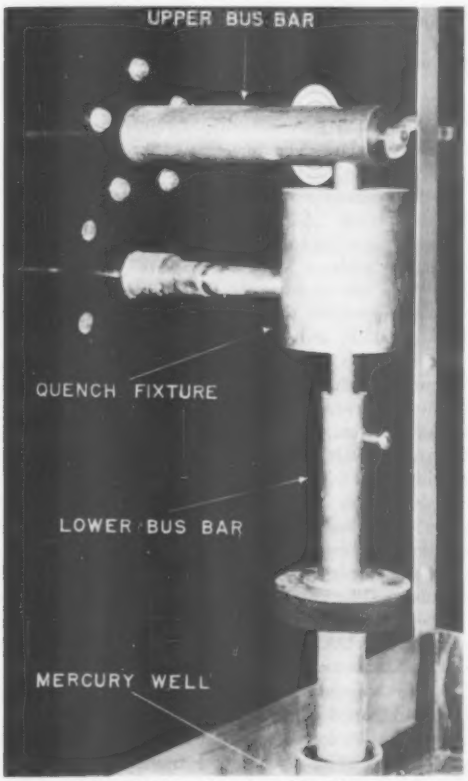

Fig. 11 Taper bar quenching fixture

All points on the cooling curves denoting the beginning of the same transformation are connected by a faired curve which, therefore, will indicate the time and temperature of the beginning of the observed reactions. The end of transformation was determined by comparing the structures obtained in the air-cooled specimen with those of specimens quenched near the end of the continuous cooling cycle (13 to 25 sec after peak temperature). When the structure obtained in the quenched specimens matched that of the air-cooled specimen the reaction was considered complete. This method of presentation eliminates the difficulty of denoting the *Ms-Mf* transformation range which is of importance primarily to a narrow region in the HAZ. The subject of martensite formation is covered in separate sections in the report.

DISCUSSION OF RESULTS

The transformations which occur in the heat-affected

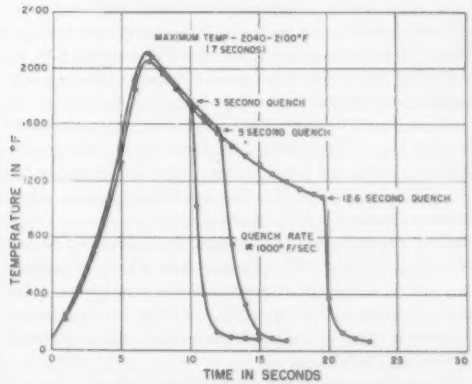

Fig. 12 Illustrating reproducibility and rate of quench of taper bar

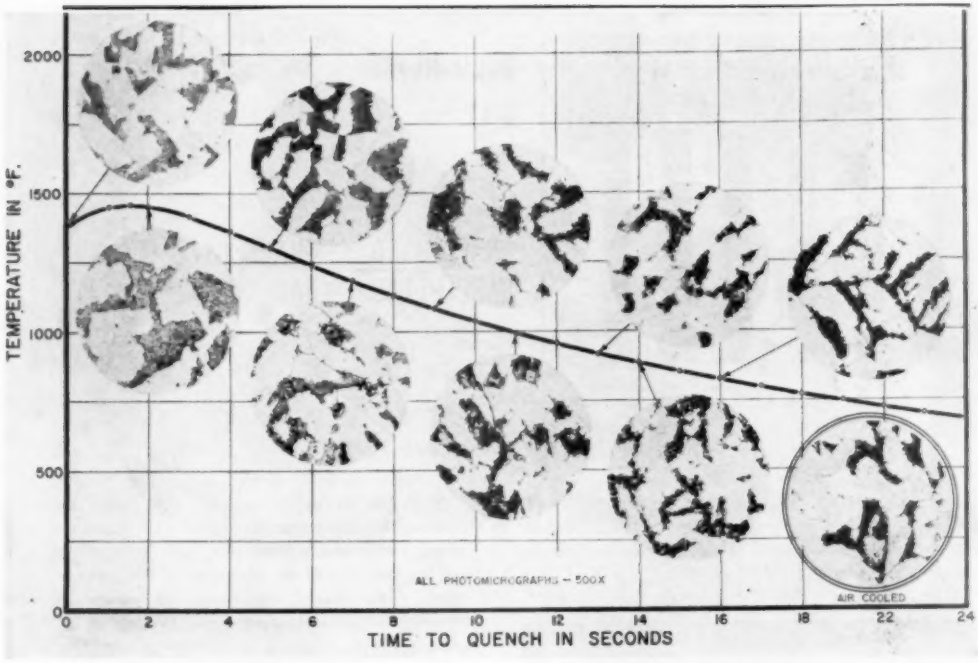

Fig. 13 Time-temperature-transformation of a region heated to 1450° F

zone fall roughly into three categories: namely (1) transformations which occur from homogeneous (or nearly so) austenites, (2) transformations which occur from heterogeneous austenites and (3) transformations which take place from the alpha plus gamma range.

The homogeneous austenite regions, which comprise the portion of HAZ nearest the line of fusion, transform by the initial rejection of proeutectoid ferrite at the austenite grain boundaries ($F_i + A$ zone). This occurs in the range of 1400–1250° F, depending on the uniformity of homogenization at the particular location. As cooling progresses additional ferrite is precipitated within the grains in Widmanstätten fashion. This phase of reaction ends at approximately 1100° F, below which carbide rejection in the form of fine carbide particles distributed in a ferritic matrix occurs ($F_i + C + A$ zone). Intermediate transformation products of this type were developed down to approximately 750° F. The end point of this reaction could not be established precisely; however, microhardness measurements indicated essential completion except for small regions which finally transformed to martensite at the Ms temperature. The dashed line which delineates the lowest temperature region of the carbide reaction zone represents the point at which the quenched structures were indistinguishable from the structures of the freely cooled bar.

The heterogeneous austenite regions which comprise the portion of the HAZ which was heated in the range of 1700–1900° F show a distinctly different transformational behavior. The rejection of proeutectoid and blocky ferrite occurs initially in the carbon-poor austenite regions representing positions of the original ferrite patches. As a result the reaction occurs in heterogeneous fashion following positions which were originally midway between pearlite patches. The higher A_3 temperatures of these low-carbon regions are responsible for the indicated higher temperatures (1550–1450° F) and shorter time of initial ferrite rejection shown by this portion of the HAZ. As cooling progresses, ferrite rejection continues by additional ferrite formation at the described regions and the starting of rejection in regions of higher carbon content, i.e., regions which were closer to or within the original pearlite areas. The slightly higher temperatures noted are deemed to result from somewhat slower cooling rates in the incompletely homogenized zone. Carbide reaction is likewise heterogeneous being concentrated in the carbon-rich regions representing the sites of original pearlite patches.

The portion of the HAZ which has been heated in the range of 1350–1600° F presents a peculiar case of continued austenitization during the cooling cycle. The peak temperatures reached in this zone during the short period of the heating cycle effectively limit austenitization to the pearlite patches with the ferrite patches remaining essentially untransformed. At the lower level of this temperature range, i.e., for the region

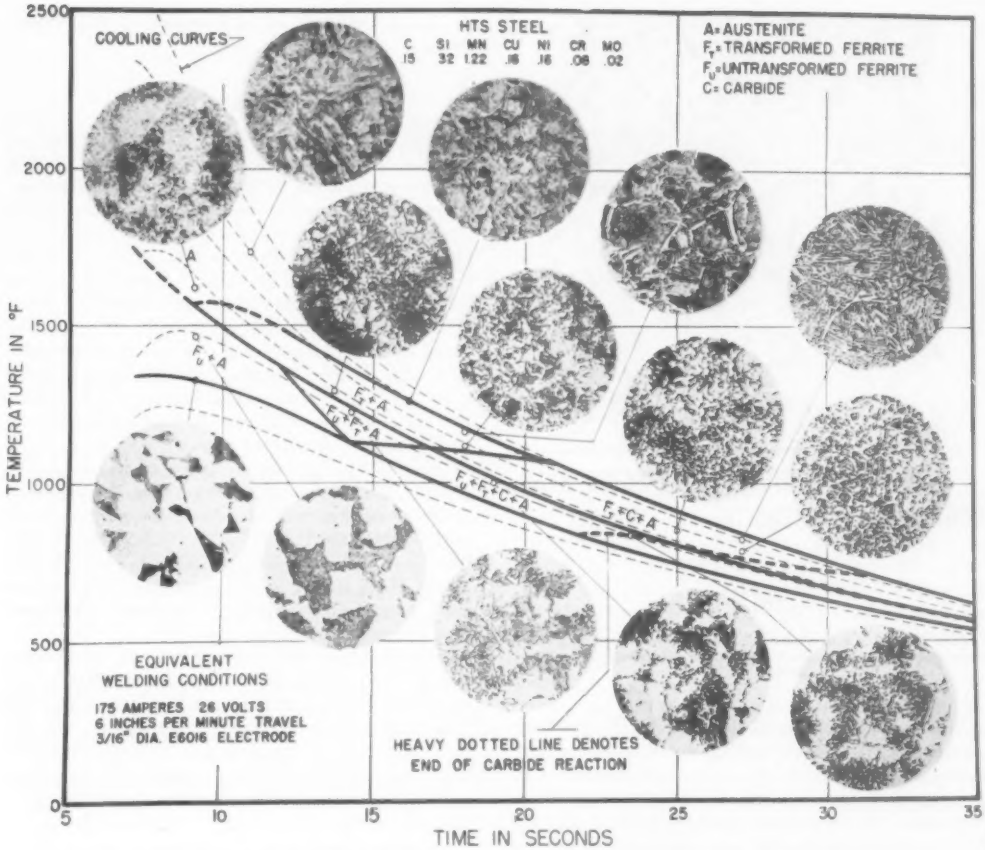

Fig. 14 Continuous cooling, time-temperature-transformation diagram, weld heat-affected diagram

that has just reached the A_1, only the pearlite areas show transformation, as is indicated by the absence of proeutectoid ferrite reaction on the diagram. At higher levels of this temperature range carbon migration from the eutectoid austenite regions occurs during the initial stages of cooling causing a carbon rise, hence austenitization of the ferrite patch regions which surrounded the original pearlite patches. The austenite pool thus grows in size during this period. On continued cooling the nature of the transformations are essentially the same as described for the heterogeneous austenite region of the HAZ. Proeutectoid ferrite reaction occurs in heterogeneous fashion, first in the last austenitized regions, then extending gradually into the portion of the original austenite pool which had fallen to below eutectoid composition by carbon. loss to the surrounding, originally ferrite areas.

It is apparent that the primary effect of the gradation of temperatures which are developed in the HAZ is on the nature of the distribution of the hypoeutectoid and eutectoid constituents. Regions which are heated to high austenitizing temperatures result in a uniform distribution of these constituents. Conversely, regions which are heated to low austenitizing temperatures result in a semicontinuous network of the eutectoid constituent, shown clearly in Fig 13. This tendency is most pronounced at temperatures which permit partial austenitization of the original ferrite areas by carbon migration during the initial stages of cooling. The tendency under this condition is to effect a junction between the austenite pools in the form of a near eutectoid austenite network which later transforms to a similar network of eutectoid reaction structures.

In view of the controlling effect of phase distribution on mechanical properties,[7] the nature of the distribution of the phases resulting from transformation of heat-affected zones should be considered of importance equal to that of the type of transformation. Thus, the method of representing transformation as to type only which is used in conventional TTT and continuous cooling TTT curves is inadequate for the case of welding.

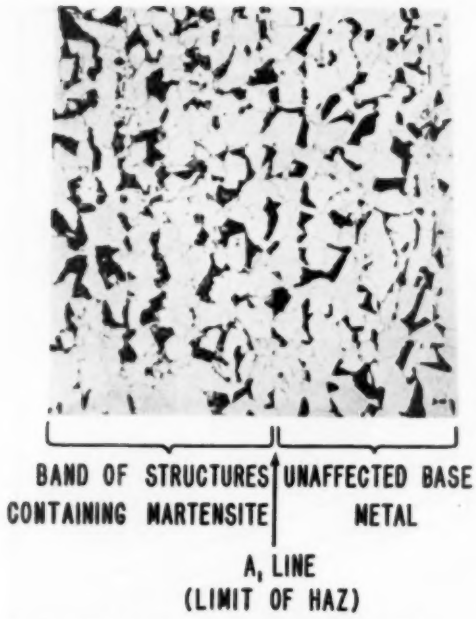

Fig. 15 Band of martensitic structures produced by transformation of high-carbon austenite (originally pearlitic) areas. × 200

Martensite formation in the subject HTS provides an example, illustrating further the danger of simple extension of metallurgical information obtained from investigations of homogeneous austenite reaction structures. In the case of HAZ positions which reached high austenitizing temperatures the final distribution of martensite was of a uniform dispersed nature and expected to be of lower carbon content, hence of lower hardness. In the case of HAZ regions which reached low austenitizing temperatures the martensite regions were concentrated in the resulting eutectoid reaction network. Figure 15 shows a band of martensite structures of 400 VPN hardness which was developed in this region. While no property studies were made, such a zone of semicontinuous martensite regions should be suspected to be potentially dangerous.

It is apparent that there exists an almost untouched field of investigation related to welding transformations and the properties of the peculiar distribution of phases foreign to the conventional field of metallurgy. More exact information is also needed concerning the temperature range of martensite formation. Preliminary experiments have indicated that, in regions which are partially austenitized and then rapidly cooled, this range is considerably lower than would be expected for low-alloy steels. Studies related to these questions are being conducted as an extension of this investigation.

CONCLUSIONS

A novel method is described for studying the continuous cooling transformations that occur in the heat-affected zone of weldments. The method utilizes a tapered section bar of small diameter through which a heavy controlled current passes to cause rapid heating and melting at the least section which effectively simulates the HAZ of the weld. Almost exact correspondence between the weld thermal cycles and those of the taper bar specimen is obtained. A number of these specimens are quenched after fusion at such times as are required to metallographically determine the beginning and end of transformation. A time-temperature-transformation diagram was constructed for an HTS steel heat-affected zone.

Three distinctly different types of transformation are noted: (1) transformation from homogeneous austenite regions, which comprise the portion of the HAZ nearest the line of fusion. (2) transformation from heterogeneous austenite regions (those regions of the HAZ heated in the range of 1700–1900° F) and (3) transformation from an austenite (high carbon) plus untransformed ferrite field.

Semicontinuous envelopes of eutectoid transformation products develop in the regions of the HAZ which transforms from heterogeneous austenite and austenite plus ferrite zones. This type of structure is not obtained by conventional heat treatment. Mechanical properties of such structural types are suspected to be inferior to the properties of conventional transformation types.

ACKNOWLEDGMENTS

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Chromium Recovery During Submerged-Arc Welding

Reactions in submerged-arc welding of stainless steel depend on flux composition and welding conditions. Best fluxes are low in manganese and silicon and high in basic compounds

by James G. Kerr and David A. Elmer

Abstract

Stainless steels are difficult to weld by submerged-arc welding Chemical reactions between the flux and weld metal occur. Chromium is lost to the flux and manganese and silicon are picked up by the weld metal. This may increase the likelihood of weld-metal cracking. The data show that the extent of these reactions depends upon flux composition and welding conditions. And the data indicate that fluxes low in manganese and silicon and high in basic compounds are best suited for submerged-arc welding high-chromium alloys.

INTRODUCTION

SUBMERGED-ARC welding has become one of industry's most important fabrication tools during the past ten years. Carbon and low-alloy steels are weldable by the submerged-arc method. Few troubles are now encountered with these materials from either weld-metal cracking or unsatisfactory weld-metal physical properties.

Stainless steels, though, do not lend themselves so well to welding by the submerged-arc process. The basic difficulty arises from chemical reactions that occur between the flux and the weldmetal. Commercially available fluxes cause considerable chromium depletion. And consequently, the weldmetal becomes contaminated with excessive amounts of silicon and manganese. Extremely crack-sensitive weldmetal is the usual result.

This report is about reactions between flux and metal that take place when stainless steels are welded by the submerged-arc process. Of primary concern are the extent, mechanism and implication of chromium depletion and consequent silicon and manganese pickup.

BACKGROUND

Several investigators[1-7] attribute the cracking of fully austenitic stainless-steel weldmetals to the presence of intergranular segregates having a low melting temperature. Carpenter and co-workers,[8] and Kudelya,[7] present evidence to identify the segregates as silicates. During weld metal solidification, these insoluble, low-melting-temperature compounds are continually rejected into the remaining melt. They collect and occur as intergranular segregates. The result is hot-short weld metal, and consequent cracking.

Other investigators show[4, 5, 8] that weld metal cracking depends on the carbon-silicon ratio. Campbell and Thomas[8] found that carbon and silicon should be held within specific limits to avoid cracking in 25–20 chromium-nickel weld metal. Carbon should be between 0.10 and 0.20%, and silicon between 0.40 and 0.60%. Carpenter and co-workers[4, 5] verified these findings and found the same to be true for 19–9 weld metals.

The presence of a small amount of delta-ferrite inhibits cracking in otherwise fully austenitic weld metals.[1-3, 8-10] One explanation for this is that during solidification, the formation of a dentritic network of delta-ferrite restricts the occurrence of extensive segregates.[11] In this way, silicates or other nonmetallics become well dispersed rather than localized as a film between columnar grains.

Control of chemical composition is necessary for the deposition of sound austenitic weld metal. Several of the minor alloying elements must not be present in too large a quantity. And the major elements should be present in amounts that allow the formation of some delta-ferrite. For these reasons, data concerning chromium recovery during submerged-arc welding are important.

There is very little information in American welding literature about flux reactions during submerged-arc welding. Several authors[12-14] give estimates of chromium and columbium recovery when welding stainless steels. These estimates vary from about 70 to nearly 100% for chromium and from 40 to 70% for columbium. No information is available about the extent of manganese and silicon pickup.

Russian workers have been active in research on submerged-arc welding. Some of their work aimed at the development of fluxes for the welding of austenitic stainless steels. Lyubavskii[15] gives data comparing the behavior of several fluxes with 18–8 weld metal. A high-manganese, silicate flux, similar to several fluxes

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Fig. 1 Welding equipment

used in America, reacts severely with molten stainless-steel weld metal. The result is poor chromium recovery, considerable pickup of silicon and manganese, and weldmetal containing large quantities of nonmetallic inclusions. Lyubavskii shows that a basic, manganese-free flux has these tendencies to a much smaller extent.

TEST WORK

This report describes four sets of experimental data. (1) A chemical balance for welds on 12% chromium stainless steel, made with ferritic stainless-steel wire and various proprietary fluxes. (2) A comparison of chromium loss from the base material with loss from the electrode. (3) A study of the effect of some changes in flux composition on chromium recovery. (4) A study of the effect of welding conditions on chromium recovery.

All welds were made with direct current at reversed polarity. Standard automatic welding equipment was used. Figure 1 is a photograph of this apparatus. Welding current and arc voltage were measured with precision laboratory-type instruments. The plate temperature was between 70 and 150° F. at the start of each weld.

All materials were of commercial quality. Table 1 is a tabulation of the material compositions. Part A lists chemical analyses and identification-codes for plate and wire, and Part B lists the analyses and indentification-codes for the various proprietary fluxes that were used.

All welds were deposited on unbeveled, sandblasted plate. The flat plate simplified the determination of weld metal dilution. Percentage chromium recovery was computed from the relation

$$(C_p \times D \times R_p) + (C_e \times (1 - D) \times R_e) = C_d$$

where

C_p = % chromium in the plate.
D = % dilution.
R_p = % chromium recovery from the plate.
C_e = % chromium in the electrode.
R_e = % chromium recovery from the electrode.
C_d = % chromium in the weld deposit.

Chromium recovery from the plate, as will be shown, is about 95%. But it is sometimes convenient to assume that all chromium lost comes from the electrode. And then R_p, above, becomes unity.

The chromium-recovery computation is only as dependable as the accuracy of the individual determinations used in making the computation. All chemical analyses represent the average of three or more values obtained through standard wet-chemical procedures. These determinations are accurate to less than 1% error.

Weld cross-section measurements and the resulting determination of dilution values can be made as accurate as is desired. The cross sections studied must represent an accurate average if the weld cross-section is not constant. This is the determining factor, since the measurements themselves can be made with extreme precision. Figure 2 shows the underside of a weld that was deposited by submerged-arc welding. This weld was made with 25–20 chromium-nickel wire

Table 1—Chemical Analyses of Materials Used

Part A—Metals

Material	Code	Cr	Mn	Si	Al	S	P	C
5/32-in. wire	430A	16.73	...	...	...	...	...	0.11
5/32-in. wire	430B	16.50	0.38	0.47	0.00	0.011	0.018	0.13
3/32-in. wire	406A	13.34	0.42	0.42	4.11	0.010	0.017	0.07
5/8-in. plate	410A	12.93	0.43	0.41	...	...	...	0.12
5/8-in. plate	405A	12.03	0.59	0.42	0.33	0.013	0.018	0.07
1/4-in. plate	410C	12.48	0.41	0.33	...	0.018	0.022	0.07
5/32-in. wire	36A	0.01	1.98	0.02	...	...	...	...
1/4-in. plate	A-285A	0.01	...	...	...	...	...	...

Part B—Fluxes

	Reported as oxides							Reported as elements					
Flux code	MnO	SiO_2	Al_2O_3	FeO	CaO, MgO, Na_2O	TiO_2	Cr_2O_3	Mn	Si	Al	Cr	Fe	Ca, Mg, Na
80A	7.6	37.3	16.8	6.5	29.8	0.3	0.8	5.9	17.4	8.47	0.55	5.0	21.2
20A	1.6	56.1	8.6	2.0	31.1	0.1	0	1.24	26.2	4.55	0	1.5	21.4
90A	26.4	38.0	17.2	5.0	10.3	2.8	0.15	20.5	17.7	9.1	0.10	3.9	9.5
660A	46.0	41.5	1.7	1.6	11.1	0	0	35.6	19.4	0.90	0	1.2	8.2
780A	40.0	43.1	3.6	6.8	1.5	1.2	0	31.0	20.1	1.91	0	5.2	2.0
80B	...	...	...	...	...	...	...	...	...	...	0.08	...	...

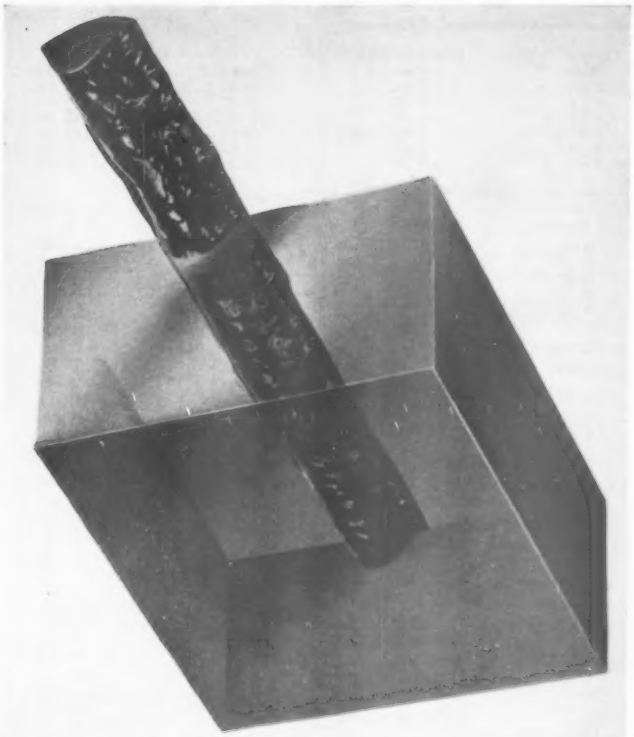

Fig. 2 Weld deposit (reduced 20% in reproduction)

on carbon-steel plate. The weld sample was then placed in a bath of boiling 50% nitric acid. This quickly corroded away the carbon steel, leaving unattacked weld metal. Measurements on this sample showed that penetration varied plus or minus about 2%. Width, plus or minus about 1%. And crown height, plus or minus about 1%.

All chromium recovery values were determined from two cross-sections. An image of each cross section was projected onto a ground-glass screen with a magnification of eight. A tracing of the weld deposit was then made. Deposit dimensions were taken from the tracings with an ordinary scale. And areas were determined with a planimeter. The greatest source of error in making these measurements is in locating accurately the boundary between the crown and base-metal. An error of 0.005-in. here will cause an error of plus or minus about 4% in the chromium recovery value. With the aid of a

Table 2—Chemical Balance Data

Part A—Welding conditions

Weld	*Wire*	*Plate*	*Flux*	*Amperes*	*Volts*	*Speed, ipm.*
A	430B	405A	80A	400	30	15
B	430B	405A	20A	400	30	15
C	430B	405A	90A	400	30	15
D	430B	405A	660A	400	30	15
E	430B	405A	780A	400	30	15
J	406A	405A	780A	400	30	15

Part B—Deposit geometry and calculations

Weld	*Crown area*	*Base area*	*Dilution, %*	*Ideal chrome %*	*Actual chrome %*	*Chromium recovery, %**	*Chromium recovery, %†*
A	0.047	0.063	57.2	13.95	13.20	94.1	89.4
B	0.053	0.071	57.3	13.95	12.92	90.1	85.3
C	0.053	0.070	56.8	13.97	12.58	85.4	80.5
D	0.050	0.060	54.5	14.07	11.98	75.3	72.2
E	0.050	0.068	57.3	13.95	11.70	72.8	68.1
J	0.059	0.075	56.2	12.61	11.55	87.7	81.8

Part C—Chemical analyses %

Weld	*Material*	*C*	*Mn*	*Si*	*Al*	*Cr*
A	Deposit	0.14	0.86	0.75	0.08	13.20
A	Fused flux	0	9.05	15.7	8.48	2.92
B	Deposit	0.09	0.29	1.12	0.06	12.92
B	Fused flux	0	1.12	23.6	3.60	3.35
C	Deposit	0.05	1.29	0.67	0.23	12.58
C	Fused flux	0	24.1	14.6	12.18	2.72
D	Deposit	0.08	1.76	0.88	0.05	11.98
D	Fused flux	0	30.1	11.6	1.48	3.54
E	Deposit	0.09	2.26	1.14	0.07	11.70
E	Fused flux	0	31.6	20.35	0.92	3.85
J	Deposit	0.10	2.29	1.51	1.03	11.55
J	Fused flux	0	31.2	20.3	5.30	2.60

* Based on 95% recovery from plate.
† Based on 100% recovery from plate.

Table 3—Weight Balance of Elements

Part A—Quantities involved, grams per inch of weld

Weld	*Plate*	*Wire*	*Flux*	*Fused flux*	*Deposit*
A	7.97	5.96	9.24	9.24	13.93
B	9.00	6.74	5.17	5.17	15.74
C	8.79	6.71	8.88	8.88	15.50
D	7.58	6.35	8.74	8.74	13.93
E	8.06	6.36	7.67	7.67	14.42
J	9.50	7.41	6.78	6.78	16.91

Part B—Element balance, grams per inch of weld

Weld	*Element*	*Plate*	*Wire*	*Flux*	*Fused flux*	*Deposit*	*Unaccounted for*
A	Chromium	0.96	0.97	0.05	0.27	1.84	+0.13
	Manganese	0.047	0.023	0.54	0.84	0.12	+0.35
	Silicon	0.033	0.028	1.61	1.45	0.11	−0.11
	Aluminum	0.026	0	0.78	0.79	0.011	−0.01
	Carbon	0.0056	0.0077	0	0	0.019	+0.005
B	Chromium	1.08	1.11	0	0.17	2.04	+0.02
	Manganese	0.053	0.026	0.064	0.058	0.046	−0.04
	Silicon	0.038	0.032	1.35	1.22	0.18	−0.02
	Aluminum	0.030	0	0.23	0.19	0.009	−0.06
	Carbon	0.0063	0.0088	0	0	0.014	−0.001
C	Chromium	1.05	1.11	0.009	0.24	1.95	+0.02
	Manganese	0.052	0.026	1.82	2.14	0.20	+0.44
	Silicon	0.037	0.032	1.57	1.30	0.10	−0.24
	Aluminum	0.029	0	0.81	1.1	0.036	+0.30
	Carbon	0.0061	0.0087	0	0	0.007	−0.008
D	Chromium	0.91	1.05	0	0.31	1.67	+0.02
	Manganese	0.045	0.024	3.11	2.73	0.25	−0.20
	Silicon	0.032	0.030	1.70	1.01	0.12	−0.63
	Aluminum	0.025	0	0.08	0.13	0.007	−0.032
	Carbon	0.005	0.008	0	0	0.011	−0.002
E	Chromium	0.97	1.05	0	0.30	1.69	−0.03
	Manganese	0.048	0.024	2.38	2.43	0.33	+0.32
	Silicon	0.034	0.030	1.55	1.56	0.16	+0.11
	Aluminum	0.027	0	0.14	0.07	0.010	−0.09
	Carbon	0.006	0.008	0	0	0.013	−0.001
J	Chromium	1.04	0.99	0	0.18	1.96	+0.11
	Manganese	0.056	0.031	2.10	2.12	0.39	+0.33
	Silicon	0.040	0.031	1.36	1.38	0.26	+0.21
	Aluminum	0.031	0.30	0.13	0.36	0.17	+0.07
	Carbon	0.007	0.005	0	0	0.017	+0.005

magnified image, this error is on the order of one or two thousandths. And the over-all accuracy of the chromium recovery data is on the order of plus or minus 3%.

Six welds were made to obtain a chemical balance for the elements carbon, silicon, manganese, aluminum and chromium. The welding conditions are shown in Part A of Table 2. The plate used is 12% chromium, meeting ASTM Specification A-240, Grade O. The wire for five welds—A, B, C, D and E—was $^5/_{32}$ in., 17% chromium, AISI Type 430. Each of these five welds was made with a different flux. The wire used for the sixth weld, J, was 12% chromium, 4% aluminum —AISI Type 406.

Table 1 lists the chemical composition of the plate, wire and flux used. Part B of Table 2 lists dilution data and chromium recovery for all six welds. Part C of Table 2 gives the analysis of the weld metal and fused flux. And Table 3 is a weight balance of elements for all six welds. Part A shows the amounts of plate, wire, flux, fused flux and weld metal involved in each weld—given in grams per inch of weld. Part B is the balance itself. Table 4 is a comparison of the actual chemical composition of these welds with the ideal composition that would occur if there were no slag reactions.

Nine submerged-arc welds were made on 12% chromium plate to determine the extent of chromium recovery from the base material. Six welds were made with carbon-steel welding wire and three with a $^1/_8$-in. tungsten electrode. Since there is no chromium in the electrode, any chromium lost will be from the base plate. Table 5 lists the data from these welds—welding conditions, weld dimensions and chromium recovery.

Table 4—Comparison of Actual and Ideal Chemical Analyses

Weld A			*Weld B*		
Actual	*Element*	*Ideal*	*Actual*	*Element*	*Ideal*
13.20	Cr	13.95	12.92	Cr	13.99
0.86	Mn	0.50	0.29	Mn	0.50
0.75	Si	0.45	1.12	Si	0.45
0.08	Al	0.19	0.06	Al	0.19
0.14	C	0.10	0.09	C	0.10

Weld C			*Weld D*		
Actual	*Element*	*Ideal*	*Actual*	*Element*	*Ideal*
12.58	Cr	13.96	11.98	Cr	14.07
1.29	Mn	0.49	1.76	Mn	0.49
0.67	Si	0.44	0.88	Si	0.44
0.23	Al	0.19	0.05	Al	0.18
0.05	C	0.10	0.08	C	0.10

Weld E			*Weld J*		
Actual	*Element*	*Ideal*	*Actual*	*Element*	*Ideal*
11.70	Cr	13.95	11.55	Cr	12.66
2.26	Mn	0.49	2.29	Mn	0.51
1.14	Si	0.45	1.51	Si	0.42
0.07	Al	0.19	1.03	Al	1.99
0.09	C	0.10	0.10	C	.07

Table 5—Data on Chromium Recovery from Base Plate

Weld	Plate	Wire code	Flux	Amperes	Speed	Volts	Width	Crown height	Penetration	Base area	Crown area	Dilution, %	Ideal % chrome	Actual % chrome	Chrome recovery, %
BZ	405A	36A	80A	300	20	30	0.518	0.06	0.07	0.0230	0.0238	49.1	5.9	5.58	94.6
CA	410C	36A	80A	300	20	30	0.513	0.06	0.09	0.0244	0.0219	52.7	6.58	6.24	94.8
CB	405A	36A	80A	400	20	30	0.650	0.08	0.15	0.0550	0.0350	61.1	7.36	6.90	93.7
CC	410C	36A	80A	400	20	30	0.613	0.06	0.17	0.0556	0.0306	64.5	8.05	7.53	93.6
CD	405A	36A	80A	500	20	30	0.700	0.09	0.21	0.0833	0.0494	63.6	7.66	7.48	97.6
CE	410C	36A	80A	500	20	30	0.688	0.09	0.23	0.0856	0.0500	63.2	7.89	7.53	95.5
AG	410A	W	80A	500	30	30	...	...	...	0.0750	0	0	12.94	12.19	94.2
AI	405A	W	80A	500	30	25	...	...	...	0.0834	0	0	12.03	11.41	94.8
AJ	405A	W	80A	500	30	25	...	...	...	0.0819	0	0	12.03	11.56	96.0

Table 6—Data on Effect of Chromium in Flux

Weld	Amperes	Volts	Speed	Wire	Plate	Flux	Times used	Chromium in flux, %	Crown area	Base area	Dilution, %	Ideal % chrome	Actual % chrome	Chromium recovery, %
CO	400	35	10	430B	A-285A	80B	0	0.08	0.0723	0.0569	44.0	9.30	7.78	83.7
CP	400	35	10	430B	A-285A	80B*	1	0.93	0.0784	0.0790	50.2	8.25	7.06	85.7
CQ	400	35	10	430B	A-285A	80B*	2	1.78	0.0711	0.0745	52.8	7.85	6.94	88.4
CR	400	35	10	430B	A-285A	80B*	3	2.54	0.0781	0.0830	51.5	8.05	7.39	91.8
CS	400	35	10	430B	A-285A	80B*	4	3.14	0.0775	0.0873	53.0	7.80	7.33	93.9
CT	400	35	10	430B	A-285A	80B*	5	3.40	0.0683	0.0650	48.0	8.64	7.92	91.8

* Reground fused-flux.

Several welds were made using fluxes containing various amounts of chromium oxide. None of the commercially available fluxes contain appreciable amounts of chromium. It was necessary then, for these experiments, to use specially prepared fluxes. This was done by first making a weld with fresh Code 80B flux. The fused flux was then reground and reused, and so on for six times. In this way, fluxes with increasing chromium content were obtained. The welds were made on carbon-steel plate using $^5/_{32}$-in., 17% chromium wire—AISI Type 430. Table 6 lists all data for these welds—welding conditions, per cent chromium in the flux, deposit dimensions, dilution and per cent chromium recovery.

Some 40 welds were made to study the dependence of chromium recovery upon welding conditions. Current, arc voltage and travel speed were studied. All of these welds were made on flat carbon-steel plate using $^5/_{32}$-in., 17% chromium wire—AISI Type 430, and Code 80A flux. Table 7 lists all data for these welds—welding conditions, deposit dimensions, dilution and per cent chromium recovery.

DISCUSSION OF DATA

Mechanism of Chromium Loss

A chemical balance was made to clarify the mechanism of chromium loss. Welds A, B, C, D and E were made with different fluxes on 12% chromium plate with 17% chromium wire. Table 4 is a comparison of the actual and ideal chemical analyses for these welds. Each weld lost a substantial amount of chromium to the flux. And each weld gained, in exchange, substantial amounts of silicon or manganese, or both. This indicates that the loss of chromium during submerged-arc welding is not outright oxidation resulting from the presence of oxygen in the arc zone. But rather, the loss of chromium occurs because chromium acts to reduce oxides of silicon and manganese that are in the flux. The data show that the extent of these reactions is dependent upon chemical composition of the flux.

Table 2 is a chemical balance for welds A, B, C, D, E and J. In several cases the accuracy of the element balance is poor. But there are many sources of error. Neither the flux, fused flux nor the weld metal is likely to be completely homogeneous—a necessary assumption to make the balance. In the case of manganese, aluminum and silicon, the error is magnified because of the relatively large amounts present in the flux and fused flux. In spite of this, the balance is sufficiently accurate to verify the mechanism of chromium loss suggested by weld metal analyses. Chromium is picked up by the fused flux as it is lost from the weld metal. And silicon and manganese are picked up by the weld metal as they are lost from the flux.

A prediction can be made about the effect of flux components on chromium recovery. From an ex-

Table 7—Data on Effect of Welding Conditions

Weld	*Plate*	*Wire*	*Flux*	*Amperes*	*Speed*	*Volts*	*Width*	*Crown Height*	*Penetration*	*Base area*	*Crown area*	*Dilution,%*	*Ideal % chrome*	*Actual % chrome*	*Chrome recovery, %*
AL	A-285A	430A	80A	250	20	30	0.410	0.074	0.057	0.0129	0.0212	37.6	10.45	9.05	86.6
AK	A-285A	430A	80A	300	20	30	0.506	0.081	0.084	0.0230	0.0290	44.2	9.35	8.06	86.2
AJ	A-285A	430A	80A	350	20	30	0.573	0.082	0.082	0.0269	0.0331	44.8	9.23	7.85	85.1
AI	A-285A	430A	80A	400	20	30	0.585	0.089	0.117	0.0371	0.0390	48.7	8.56	7.34	85.7
AM	A-285A	430A	80A	450	20	30	0.620	0.106	0.153	0.0532	0.0471	53.0	7.85	6.72	85.6
AN	A-285A	430A	80A	500	20	30	0.666	0.126	0.164	0.0632	0.0546	53.7	7.75	6.77	87.4
AO	A-285A	430A	80A	550	20	30	0.670	0.163	0.225	0.0855	0.0620	58.0	7.03	6.02	85.6
AP	A-285A	430A	80A	600	20	30	0.659	0.162	0.209	0.1094	0.0699	61.0	6.53	5.63	86.3
AQ	A-285A	430A	80A	650	20	30	0.644	0.188	0.346	0.1329	0.0794	62.4	6.29	5.41	86.0
AU	A-285A	430A	80A	400	20	25	0.545	0.119	0.108	0.0350	0.0414	45.8	9.07	7.88	86.8
AT	A-285A	430A	80A	400	20	27.5	0.585	0.093	0.120	0.0388	0.0412	48.4	8.64	7.39	85.4
AI	A-285A	430A	80A	400	20	30	0.585	0.089	0.117	0.0371	0.0390	48.7	8.56	7.34	85.7
AS	A-285A	430A	80A	400	20	32.5	0.621	0.089	0.136	0.0420	0.0405	50.9	8.22	6.76	82.3
AR	A-285A	430A	80A	400	20	35	0.636	0.081	0.146	0.0487	0.0388	55.6	7.44	6.29	84.5
AV	A-285A	430A	80A	400	20	37.5	0.665	0.077	0.134	0.0444	0.0380	53.9	7.72	6.38	82.6
AW	A-285A	430A	80A	400	20	40	0.704	0.081	0.137	0.0503	0.0393	56.1	7.36	6.21	84.4
AX	A-285A	430A	80A	400	20	42.5	0.726	0.076	0.143	0.0535	0.0378	58.6	6.93	5.83	84.1
AY	A-285A	430A	80A	400	20	45	0.710	0.079	0.161	0.0600	0.0396	60.3	6.65	5.57	83.7
AZ	A-285A	430A	80A	400	20	47.5	0.670	0.082	0.165	0.0623	0.0380	62.1	6.35	5.26	82.8
BK	A-285A	430A	80A	400	10	22.5	0.613	0.190	0.168	0.0599	0.0832	41.8	9.75	8.47	86.8
BJ	A-285A	430A	80A	400	10	25	0.696	0.148	0.191	0.0672	0.0768	46.6	8.95	7.71	86.2
BI	A-285A	430A	80A	400	10	27.5	0.715	0.140	0.175	0.0638	0.0733	46.5	8.96	7.47	83.3
BH	A-285A	430A	80A	400	10	30	0.785	0.131	0.202	0.0790	0.0769	50.6	8.28	6.83	82.5
BG	A-285A	430A	80A	400	10	32.5	0.841	0.126	0.191	0.0783	0.0800	49.4	8.48	6.83	80.6
BF	A-285A	430A	80A	400	10	35	0.886	0.124	0.187	0.0797	0.0811	49.6	8.45	6.71	79.3
BE	A-285A	430A	80A	400	10	37.5	0.929	0.121	0.164	0.0718	0.0804	47.3	8.83	6.87	78.0
BD	A-285A	430A	80A	400	10	40	0.969	0.108	0.163	0.0765	0.0765	50.0	8.38	6.64	79.3
BC	A-285A	430A	80A	400	10	42.5	0.988	0.110	0.168	0.0738	0.0730	50.6	8.27	6.55	79.2
BB	A-285A	430A	80A	400	10	45	1.025	0.110	0.176	0.0781	0.0803	49.3	8.49	6.52	76.8
BA	A-285A	430A	80A	400	10	47.5	1.020	0.105	0.172	0.0795	0.0747	51.5	8.12	6.27	77.2
CN	A-285A	430A	80A	400	10	50	1.126	0.114	0.185	0.0965	0.0869	52.6	7.94	6.01	75.8
BN	A-285A	430A	80A	400	4	30	1.200	0.210	0.247	0.1340	0.1997	40.1	10.02	7.67	76.3
BO	A-285A	430A	80A	400	8	30	0.953	0.132	0.177	0.0800	0.0950	45.7	9.10	7.36	80.8
BH	A-285A	430A	80A	400	10	30	0.785	0.131	0.202	0.0790	0.0769	50.6	8.28	6.83	82.5
BP	A-285A	430A	80A	400	12	30	0.807	0.105	0.131	0.0546	0.0621	46.8	8.81	7.27	82.4
BQ	A-285A	430A	80A	400	16	30	0.709	0.091	0.143	0.0488	0.0478	50.3	8.83	7.39	83.5
AI	A-285A	430A	80A	400	20	30	0.715	0.140	0.175	0.0371	0.0390	48.7	8.56	7.34	85.7
BR	A-285A	430A	80A	400	24	30	0.573	0.071	0.115	0.0365	0.0321	53.3	7.82	6.72	85.8
BS	A-285A	430A	80A	400	28	30	0.530	0.070	0.109	0.0317	0.0267	54.3	7.68	6.46	85.2
BT	A-285A	430A	80A	400	32	30	0.498	0.065	0.112	0.0313	0.0244	56.1	7.35	6.30	85.7
BU	A-285A	430A	80A	400	36	30	0.491	0.066	0.115	0.0331	0.0231	58.9	6.88	6.04	87.8
BV	A-285A	430A	80A	400	40	30	0.456	0.064	0.123	0.0306	0.0194	61.2	6.50	5.74	88.3
BW	A-285A	430A	80A	400	50	30	0.415	0.056	0.128	0.0319	0.0156	67.1	5.51	5.16	93.5

amination of Tables 2B and 1B, the fluxes that give higher chromium recovery are seen to be higher in calcium, magnesium, sodium and aluminum and lower in manganese and silicon. And conversely the fluxes higher in manganese and silicon give lower values of chromium recovery. These results suggest that fluxes made of oxides of elements more active than chromium are not reduced by chromium. And the presence of these elements reduces the amount of reaction between chromium and compounds of manganese and silicon.

Weld J was made with the same type of flux as Weld E. But instead of 17% chromium wire, a wire containing about 12% chromium and 4% aluminum was used. Aluminum has a higher affinity for oxygen than does chromium. And here, less chromium was lost, but a substantial quantity of the aluminum was lost. The silicon and manganese pickup was large.

It is likely that chromium is lost in two ways during submerged-arc welding: By chemical reactions involving oxidation of the filler metal during passage through the arc and by reactions between weld metal and flux in the molten puddle. The nine welds of Table 5 show an average chromium recovery of 95% from the plate. The average recovery form the electrode under similar welding conditions is about 86%. It seems reasonable that the recovery from the plate should be greater than that from the electrode because the plate material is not subject to the high-temperature reactions that occur in the arc stream.

Several welds were made to determine the effect of chromium in the flux. The data for these welds are given in Table 6. Fluxes containing from 0.08 to 3.4% chromium were used. Figure 3 is a plot of chromium recovery from the electrode versus per cent chromium in the flux. This curve shows that the loss of chromium to the flux is halved as the amount of chromium in the flux is increased to about 3%. Above 2.5%, the amount of chromium in the flux seems to have less effect. The increase in chromium recovery is due not only to the presence of chromium in the flux, but also to lowered silicon and manganese contents. Reusing the fluxes reduced the manganese and silicon in amounts proportional to the increase in chromium. But the effect of reduced manganese and silicon should be less than that of increased chromium because of the relatively large amounts of silicon and manganese present at the start. Silicon starts at about 17%. Manganese starts at about 6%. And their loss corresponds to the gain in chromium of about 3%.

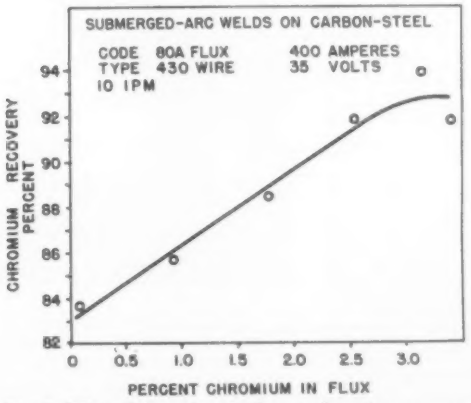

Fig. 3 Effect of chromium in flux on chromium recovery

It can be concluded that the mechanism of chromium loss in submerged-arc welding is one of reduction of the oxides of manganese and silicon in the flux by chromium metal. These reactions probably take place in both the arc zone and in the molten puddle. That the loss is by flux-metal reactions is substantiated by the element balance made and by the influence of elements other than chromium, manganese and silicon.

The presence of a metallic element more easily oxidized than chromium, such as aluminum, improves chromium recovery. This is because the more active element, aluminum, reacts with the flux instead of the chromium. Aluminum additions should not be used to improve chromium recovery because of the large additions of manganese and silicon to the weld metal. The presence in the flux of large quantities of the oxides of calcium, magnesium and aluminum means less chromium loss because chromium metal is less able to reduce these oxides than those of manganese and silicon.

Effect of Welding Conditions

Stainless steels are submerged-arc welded on a production basis in spite of the occurrence of undesirable flux-metal reactions. But the welding-engineer must minimize the extent of these reactions. It is essential to use a flux composition that has only a small tendency to cause chromium depletion. And, in addition, it is important to use welding conditions that minimize chromium depletion.

Chromium depletion and consequent weld metal contamination seem to result from high-temperature chemical reactions similar to the slag reactions that occur in steel making. Welding conditions are likely to influence the extent of these reactions. To study this, about 40 welds were made on carbon-steel plate with 17% chromium wire under controlled welding conditions. Chromium recovery was carefully determined for each weld.

It was shown earlier that flux-metal reactions occur in the arc column as well as in the weld puddle. It would seem likely, then, for chromium recovery to depend on arc length. Figure 4 shows the effect of arc voltage on chromium recovery. Two sets of data are presented. One set for welds made at 10 in. per minute travel speed. And another set for welds made at 20 in. per minute. The other welding conditions were the same for both sets of data. These data show

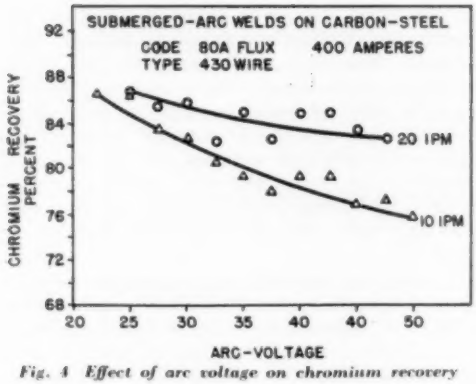

Fig. 4 Effect of arc voltage on chromium recovery

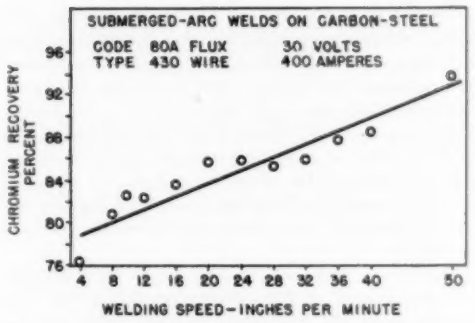

Fig. 6 Effect of welding speed on chromium recovery

that chromium depletion tends to increase as arc voltage, or arc length, is increased.

Welding current does not have a significant effect on chromium depletion. This is shown in Fig. 5. As welding current increases, greater amounts of weld metal and flux become involved in the welding process. And cooling rates are lowered. It would not be surprising if chromium depletion had increased with increased welding current. But this does not seem to be the case. Chromium recovery is independent of welding current for the welding conditions studied.

Like arc voltage, welding speed has an influence on chromium loss. Figure 6 shows this effect. Increasing the travel speed increases the chromium recovery. This can be caused by two effects. First that the proportion of flux to metal is smaller and there is less flux to react with the chromium. And second the puddle freezes faster at high travel speeds leaving less time for reaction.

CONCLUSIONS

The data reported in this paper show that chemical reactions between the flux and weld metal occur during submerged arc-welding. These reactions are of the oxidation-reduction type. Chromium is lost to the flux, and manganese and silicon are picked up by the weldmetal. This upsets the composition balance of austenitic weldmetals and can lead to cracking.

The extent of these reactions depends on flux composition. Fluxes that are low in manganese and silicon and high in the basic compounds seem best suited for submerged-arc welding of stainless steels.

Flux-metal reactions occur in both the arc column and in the weld puddle. The chromium recovery from the plate is greater than that from the electrode because the plate material is not subject to the reactions that occur in the arc stream.

Welding conditions influence the extent of flux metal reactions. Chromium recovery tends to increase as arc voltage is decreased and as travel speed is increased. Welding amperage seems to have no effect on chromium recovery.

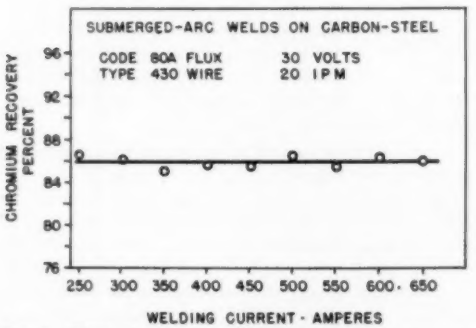

Fig. 5 Effect of welding current on chromium recovery

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Effect of Strain-Temperature History on the Low-Temperature Properties of Ingot Iron

INSIGHT into the effect of the strain-temperature history and strain aging of specimens of ingot iron on their tensile properties at low temperatures is provided by a recent study[1] conducted by G. W. Geil and N. L. Carwile of the National Bureau of Standards. Tensile specimens were extended at selected temperatures, ranging from −196 to +100° C, to specified strain values and were subsequently extended to fracture at different temperatures within the above range. By comparing the tensile data obtained in these tests with those of specimens extended to fracture in single-stage tests at the same temperatures, much valuable information on the combined effect of previous strain and temperature was obtained. This study was carried out as part of an extensive NBS investigation of the deformation of metals at low temperatures.

The manner in which metals deform, with ultimate failure or fracture depends on a number of factors. At high temperatures metals creep, i.e., extend plastically at stresses below the yield strength. At room temperatures, the different metals vary greatly in their ductility at fracture. At subzero temperatures, some metals and steels become noticeably embrittled, whereas other steels and certain nonferrous alloys may be tougher than at room temperature. To obtain a better understanding of the factors involved, the Bureau is conducting a long-range investigation of the flow, fracture and ductility characteristics of metals and alloys over a wide range of temperatures.

In recent years, several investigations have clearly indicated that the true[a] stress-strain relationship for metals and alloys extended in tension depends not only on the instantaneous values of strain, strain rate and test temperature but also on the previous strain-temperature history of the specimen. However, very little information has been available on the effect of

[a] In computing "true stress," the reduction in cross-sectional area of the specimen during extension is taken into account.

Fig. 1 An ingot iron specimen, immersed in a bath of liquid nitrogen, is tested in tension at the National Bureau of Standards. The Bureau is conducting a general investigation of the mechanical properties of metals at low temperatures

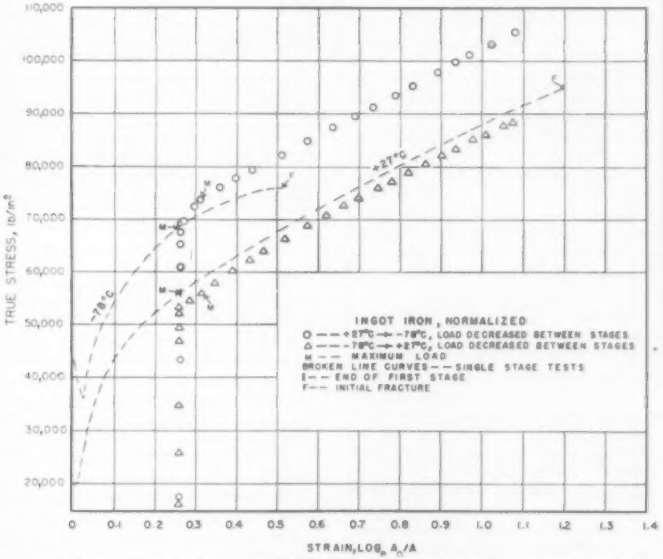

Fig. 2 True stress-strain values obtained by the National Bureau of Standards for normalized ingot iron specimens extended in tension in two-stage tests

The circles represent the values obtained during the extension at −78° C (second stage) of a specimen that had been previously extended to the maximum load at +27° C (first stage). Similarly, the triangles represent the true stress-strain values obtained during the extension at −27° C (second stage) of a specimen that had been previously extended to the maximum load at −78° C (first stage). By comparison of these two curves with the corresponding broken-line curves for the single-stage tests at −78° C and +27° C, the effect of prior strain-temperature history on the tensile properties of the material can be determined.

The relative positions of the second-stage test values in comparison with the single-stage curves indicate that strain aging during deformation at +27° C is very pronounced. This follows since the work hardening (strain hardening plus strain aging) during the deformation to maximum load at +27° C is evidently much greater than the work hardening during deformation to the same strain value at −78° C, even though strain hardening is known to be greater at −78° C than at +27° C. The cold working of the specimen during the extension to maximum load at +27° C greatly decreased its brittleness at low temperature, as shown by the increased ductility during extension to fracture at −78° C.

previous strain-aging on the stress-strain relationship. The NBS study thus fills an important gap in present knowledge of the low-temperature properties of metals.

On the basis of processing and previous heat treatment, the ingot iron samples studied by NBS could be classified as (1) annealed, (2) hot-rolled, (3) quenched and tempered, (4) normalized or (5) cold-drawn. They were all machined into cylindrical tensile specimens and were extended in tension to specified strain values in a pendulum-type hydraulic testing machine of 50,000 lb capacity. While undergoing deformation, the specimens were kept completely submerged in a liquid bath maintained at the desired temperature, except in those tests made at room temperature. Through use of a specially designed reduction-in-area gage[2] developed at NBS in 1949 for low-temperature application, the diameter of each specimen was measured during extension to an accuracy of ± 0.0001 inch.

The specimens were first extended at selected temperatures ranging from −196 to +100° C. After an interval of about one-half hour, they were again extended—this time to fracture—at a different temperature within the same range. During the interval between the two stages of each test, the specimen was maintained at the lower temperature in order to minimize any strain aging of the iron during this period. Simultaneous load and diameter measurements were made throughout the course of each stage of deformation, and true stress-strain curves were plotted from these data. The deviation of the true stress-strain curve for the second stage of the tension tests from the true stress-strain curve for a single-stage test at the same temperature as that used in the second stage gave a measure of the effect of the strain-temperature history during the first stage of the test on the tensile properties of the metal.

For ingot-iron specimens extended in tension in the temperature range studied, the total work hardening (increase in true stress with true strain) is mainly the resultant of the two processes known as strain hardening and strain aging. Strain hardening is caused by crystal deformation and increases as the testing temperature is lowered. Strain aging, on the other hand, is generally associated with the precipitation of an element from solid solution and increases (within certain limits) with rise in temperature. The work hardening of ingot iron during deformation in tension at temperatures below −120° C is mainly strain hardening; thus at these temperatures the total work hardening increases with lowering of the temperature. However, as the testing temperature is raised above −120° C, the strain aging during the deformation of the specimen increases sufficiently to become a dominating factor, and the work hardening then increases with increase in testing temperature.

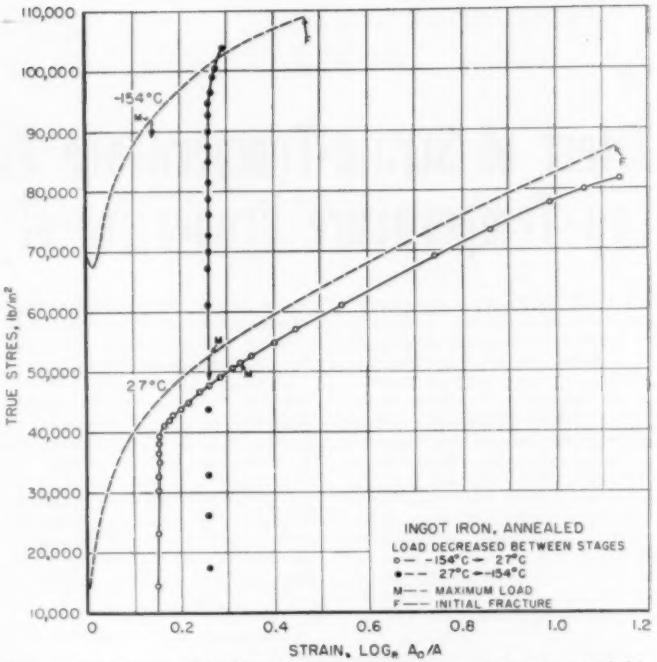

Fig. 3 True stress-strain values for annealed ingot iron specimens extended in tension at the National Bureau of Standards in two-stage tests

The closed circles represent true stress-strain values obtained during the extension at −154° C of a specimen that had been previously extended to the maximum load, M, at +27° C. The open circles represent the true stress-strain values obtained during the extension at +27° C of a specimen that had been previously extended to the maximum load at −154° C. The broken-line curves show the true stress-strain relationship at the indicated temperatures for specimens extended to fracture in a single-stage test. As a result of the pronounced strain aging at +27° C, the work hardening of the specimen during extension to maximum load at −154° C was less than that of a specimen extended to the same strain at +27° C, as indicated by the lowering of the true stress values for the second-stage test at +27° C with respect to the curve for the single-stage test at +27° C. Cold working during the extension to maximum load at +27° C caused the specimen to show greater brittleness in subsequent extension at low temperatures, as indicated by the very small strain during the extension to fracture at −154° C.

The relative proportions of strain aging and strain hardening at the various temperatures for the five conditions of the ingot iron were determined on the basis of the known tendencies of these two types of work hardening to increase or decrease with temperature. Until now the general opinion has been that strain aging of ingot iron is insignificant at subzero temperatures. However, the data obtained by the Bureau show that strain aging has a pronounced effect on the true stress-strain relationship of ingot iron specimens extended in tension at temperatures as low as −120° C.

The results of the study also shed new light on the so-called "rheotropic" brittleness of ingot iron. Some investigators have recently reported that a part of the brittleness in steels and other metals at low temperatures can be removed by cold work at temperatures above that of the transition range from ductile to brittle behavior. Such brittleness has been termed rheotropic, and a large part of the deficiency in ductility of annealed steels and some other metals at low temperatures has been reported to be rheotropic.

The data obtained in the NBS investigation show that the rheotropic brittleness of ingot iron depends upon the initial condition of the specimen. For example, it was found that cold working of hot-rolled or normalized specimens by extension in tension at room temperature removed some of their brittleness at low temperatures, whereas similar cold working of annealed specimens increased their low-temperature brittleness.

References

1. For further technical details, see "Effect of Strain-Temperature History on the Flow and Fracture of Ingot Iron at Low Temperatures," by G. W. Geil and N. L. Carwile, *J. Research NBS*, **48**, 349 (1952). RP2329. See also "Tensile Properties of Ingot Iron at Low Temperatures," by G. W. Geil and N. L. Carwile, *Ibid.*, **45**, 129 (1950). RP2119.

2 "A Reduction-of-Area Gage for Low-Temperature Application," *NBS Tech. News Bull.*, **34**, 24 (Feb. 1950).

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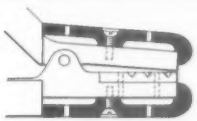

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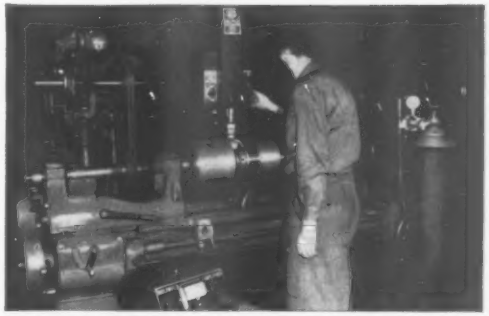

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